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BUREAU OF RECLAMATION  
HYDRAULIC LABORATORY

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AN ESTIMATE OF THE MAGNITUDE OF THE DEGRADATION WHICH WILL RESULT IN THE  
MIDDLE RIO GRANDE CHANNEL FROM THE CONSTRUCTION OF THE PROPOSED SEDIMENT  
STORAGE BASINS AND CONTRACTION WORKS

AND

SAMPLE COMPUTATIONS SHOWING METHOD OF COMPUTING  
DEGRADATION OR AGGRADATION ON THE MIDDLE RIO GRANDE RIVER

AN ESTIMATE OF THE MAGNITUDE OF THE DEGRADATION WHICH WILL RESULT IN THE  
MIDDLE RIO GRANDE CHANNEL FROM THE CONSTRUCTION OF THE PROPOSED SEDIMENT  
STORAGE BASINS AND CONTRACTION WORKS

OUTLINE

Statement of the Problem  
Cooperation with Other Agencies  
General Results and Conclusions of Study  
Quantitative Results of Degradation Estimates  
Possibilities of Increasing Degradation Rates  
Effect of Water Temperature on Degradation Rates  
Limit of Degradation  
Further Data and Studies Required to Perfect Estimates of Degradation  
Rates

Appendix I     DETAILS OF METHOD OF ESTIMATING DEGRADATION RATES  
Appendix II    DEPTH OF RIVERBED SCOUR DURING FLOODS  
Appendix III   EFFECT OF TEMPERATURE ON SEDIMENT TRANSPORTATION

Denver, Colorado

July 15, 1948

Memorandum

To: Chief Engineer

From: E. W. Lane

Subject: An estimate of the magnitude of the degradation which will result in the Middle Rio Grande River Channel from the construction of the proposed sediment storage basins and contraction works.

Statement of the Problem

1. For a considerable number of years the channel of the Middle Rio Grande has been aggrading, until it is now seriously menacing the welfare of the valley. For example, the river bottom is now higher than the streets of Albuquerque, the principal city of the valley. Not only does this situation threaten the valley with floods, but the rising bed causes an increase in the height of the groundwater table, which, if continued, will waterlog the agricultural land and thus destroy the crops of the valley. Remedial measures are absolutely necessary if this valley is to continue to be productive.

2. The causes of this situation are two fold, (1) the use of much of the water for irrigation which formerly flowed down the Rio Grande River and carried down the sediment brought into the stream channel by the tributaries, and (2) the increased load of sediment brought into the channel by the tributaries, as a result of overgrazing of the watershed. In recent geological time the river formed a valley in which there was a rough balance between the slope of the river, the stream discharge and the amount of sediment brought into the stream channel. Under these conditions the river carried down nearly all of the sediment brought down to it, and the valley floor was raised only very slowly. The white man has taken away from this section of the river a large part of the flow which it formerly had and has increased the amount of the sediment brought in, with the result that the reduced flow is insufficient to carry the increased load of sediment, and a large deposition is occurring, which is raising the river bed.

3. To protect the valley against this menace an engineering plan has been proposed by the Bureau of Reclamation and the United States Engineer Department which consists, in the main, of the construction of three large reservoirs for the temporary storage of flood waters and for the storage of most of the sediment which now comes into the upper end of the Middle Rio Grande Valley. It is expected that the amount of sediment

stored will be sufficient so that the balance will not only be restored, but will be tipped in the opposite direction, and that the present reduced river flow will then be more than enough to carry out the reduced load of sediment supplied to this stretch of the river. The river flow will therefore pick up from the bed some of the material formerly deposited and cause a lowering of the bed levels, thus reducing the groundwater levels and increasing the flood-carrying capacity of the river. It was also proposed that this degrading action would be further increased by the confinement of the river below the dams to a narrow channel, which will increase the river's capacity to carry sediment and thus accelerate its rate of lowering.

4. The purpose of the study described in this report was to estimate the rate at which the lowering of the riverbed downstream from the sediment storage basins will take place. Although the general principles involved in this action are well understood, the details of it have never been adequately studied. In connection with the investigation for the improvement of the Lower Colorado River, a similar study was made and many of the changes which have occurred there were predicted. Due to the lack of time and a sufficiently adequate knowledge of sediment transportation laws however, it was not then possible to make adequate quantitative predictions. A great advance in knowledge of sediment science has been made since the Colorado River studies were made, and a much better technique of solution has been developed for this study. Sufficient time and funds have not been available, however, to collect all of the data necessary for a highly accurate solution, nor is the present state of knowledge of sediment transportation and river scour yet sufficiently developed for this purpose. The results obtained are believed to be the best that was possible with the resources available. The study has served, not only to give approximate estimates of degradation rate with the confining channel and to point out the further studies which are necessary to perfect these estimates, but also to point out several ways in which these rates may be increased, in order that the magnitude of the lowering rate may be satisfactory.

#### Cooperation with other Agencies

5. This study was instigated by the Sedimentation Subcommittee of the Federal Inter-Agency River Basin Committee, who sponsored a meeting at Albuquerque, New Mexico, on January 6 to 9, 1947, to "review methods applicable to determining the effects of proposed...reservoirs on sedimentation in the river channel and floodways through the Middle Rio Grande Valley." In addition to the representatives of the Bureau of Reclamation, this conference was attended by men from the Corps of Engineers, Geological Survey, Forest Service and Soil Conservation Service. At this meeting, methods of estimating the degradation which would result from the reservoirs were described by Dr. H. A. Einstein and by E. W. Lane. It was recommended by this group that these men be directed by the Corps of Engineers and

Bureau of Reclamation respectively, to make studies by their methods of the degradation of the Middle Rio Grande Channel due to the sediment storage in the dams proposed for its improvement, which recommendations were approved by the respective organizations. To supply data necessary for carrying out these studies a joint program was agreed upon which would consist of:

a. The collecting together of all data on the mechanical analyses of the riverbed materials by the Soil Conservation Service and the Corps of Engineers.

b. Three borings in the riverbed, and numerous probings at ranges about 10 miles apart, together with mechanical analysis of the samples from the various depths in the borings. The field work was to be carried out by the Corps of Engineers, and the laboratory work by the Geological Survey.

c. A longitudinal profile of the river in 1936 and 1941, and characteristic cross-sections of the floodways to be compiled from the records of the Soil Conservation Service, Corps of Engineers, and Bureau of Reclamation by the respective organizations.

d. Samples of suspended sediment and of bed material to be taken at a number of gaging stations by the Geological Survey and Mechanical analyses made of them.

e. Flow duration curves of the river at various key points for the years 1936 to 41, to be compiled by the Bureau of Reclamation. These assignments were carried out by the respective agencies and the data thus collected formed the basis for this study.

6. This report is a record of the degradation estimate prepared, as suggested by this meeting.

#### Methods of Computation

7. The method of computation of the rate of degradation consisted of dividing the river into sections or reaches and computing the volume of sediment carried out of each section by the flowing water. The difference between this volume and that brought into the section from the section upstream would be the degradation in the section. Since there was some local sediment inflow and some sediment was also removed in the irrigation water, corrections were made to account for these quantities. Knowing the net volume of material removed per year from each section, the average lowering of the river channel was readily computed.

8. The sediment removed from the bed by clear water consists of a larger proportion of small particle sizes than exists in the bed material, which causes the bed material to become gradually coarser as time goes on. This in turn causes the amount of material carried out to become smaller, since the stream can carry less coarse than fine material. In the computations these effects were taken into account. Since, so far as known, no attempt has previously been made to make computations of this kind, it was necessary to develop the methods used. These methods proved to be quite detailed, but since it is desirable to record them so that they may be used in the solution of other degradation problems, they are given in detail in Appendix I.

#### General Results and Conclusions of the Study

9. The results of this study are very valuable in pointing out the need for further study of the problem and the nature of the studies required to determine the degradation which would take place, rather than in giving exact answers as to the magnitude of the degradation. It has shown that at the present time knowledge of sediment science is not sufficiently developed to enable exact predictions to be made.

10. The most important conclusion from the study is that if a confined channel is constructed below the sediment storage dams in which the sediment picked up from the bed is carried through the length of the channel to the lower end, without deposit along this course, the rate of degradation will very probably be so low as to be unsatisfactory, and that at some reaches along the channel it may even aggrade instead of degrading. To accomplish degradation at a reasonable rate it will be necessary to store the sediment picked up from the channel bottom at some point along the channel and release the clarified water back into the channel, where it will pick up another load of sediment from the channel bottom, thus increasing the rate of degradation. The rate of lowering will depend upon the number of times the same water can be induced to pick up a load from the channel bottom and deposit it in a prepared place outside the channel. It was not possible in these studies to determine this.

11. Even with very favorable assumptions on the depth to which the flowing water turns over the bed material, the rate of degradation for a regulated channel 600 feet wide, with peak flood flows in the river reduced to 5,000 cfs would reach only about 1.3 feet for the stretch between Cochiti and Angostura Dams in 50 years. In the reach between Angostura Dam and Atrisco Heading it would reach a depth of about 3 feet in 50 years, but below this point it would either change very little or aggrade. The magnitude of these changes during the 50-year period is shown on Figure 1.

12. The studies showed that the depth of degradation for the stretches covered by the computations would be larger for the contracted than for the natural channel, even if the depth of the bed material turned over by the water in the narrow channel was no greater than in the wide channel. With no change of turnover depth, the increase of maximum flow from 5,000 to 7,500 cfs would increase the degradation in the contracted channel only

# MIDDLE RIO GRANDE DEGRADATION STUDIES

- 1<sup>st</sup> Stretch — Cochiti Diversion Dam to Angostura Diversion Dam.
- 2<sup>nd</sup> Stretch — Angostura Dam to Atrisco Heading
- 3<sup>rd</sup> Stretch — Atrisco Heading to Isleta Diversion Dam.
- 4<sup>th</sup> Stretch — Isleta Dam to San Juan Heading.
- 5<sup>th</sup> Stretch — San Juan Heading to Rio Puerco.

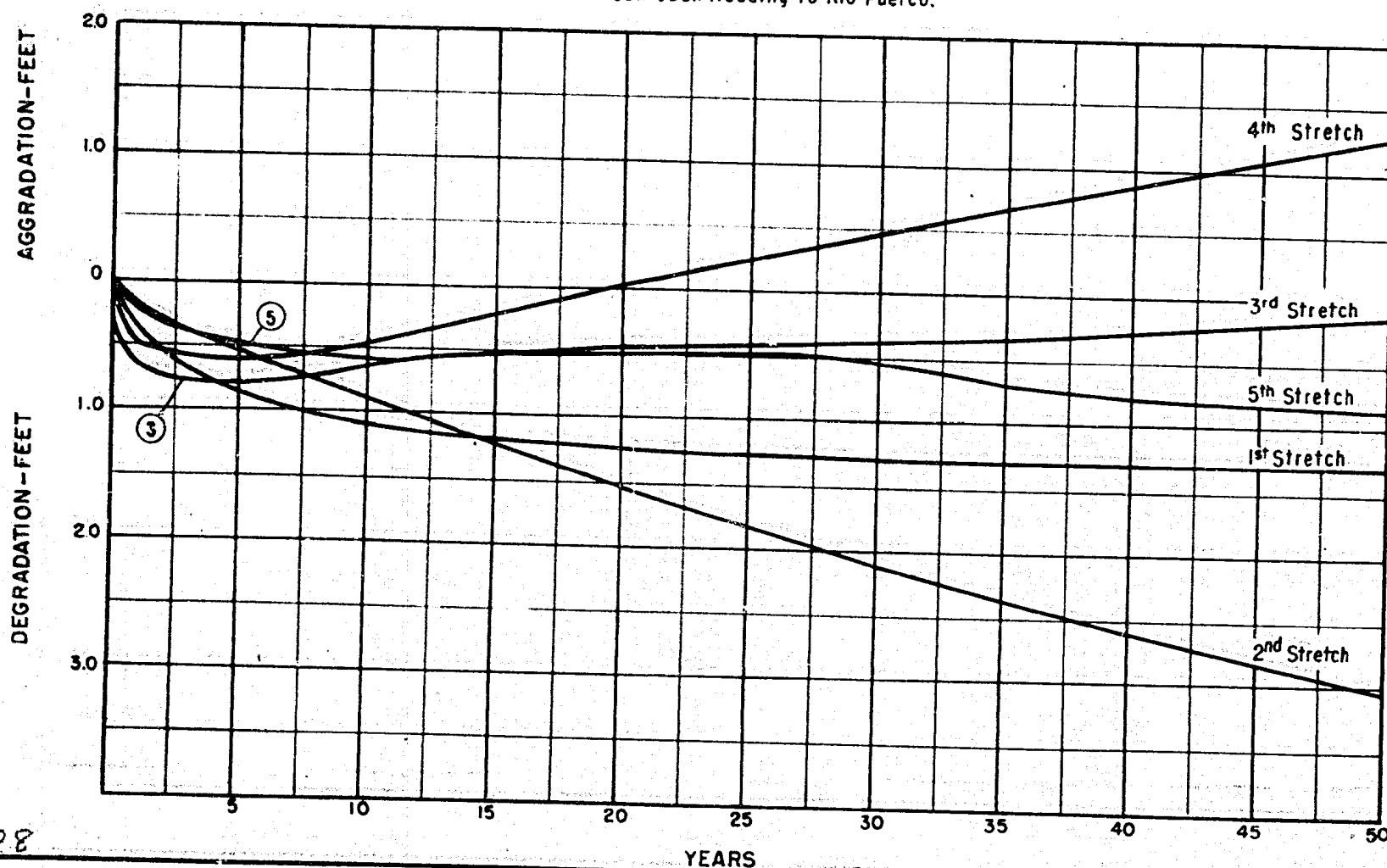


FIGURE 1

slightly. The difference between the effects of a series of high-flow years or low-flow years as compared with average years would not be great. The results which would actually occur would be considerably influenced by the volume of sediment brought in by local inflows. These occur only at unpredictable irregular intervals, and their magnitudes are difficult to estimate. However, in many cases these inflows would be capable of being handled separately.

13. The computations showed that the depth to which the bottom material was turned over by the flowing water had a large influence on the degradation depth. A small change of particle size would also cause considerable change in the degradation depth. The computations also showed that the capacity of the stream to carry sediment was a very important factor in determining the degradation rate.

14. The foregoing results show the necessity of further studies if the degrading effect of the reservoirs is to be accurately predicted. To determine the extent to which the water can be induced to drop its load at selected points outside the channel and pick up a new load from the bed, a series of hydraulic model tests should be carried out. The large effect of the depth to which the bed is turned over, on the degradation rate, shows the importance of an accurate determination of the depth to which this action takes place. The important effect of particle size on degradation rate shows the necessity of an accurate knowledge of the size of material through which the channel would run, and therefore the need to supplement the meager data on this point by further sampling. The large influence of the transporting capacity of the stream emphasizes the necessity of determining this capacity accurately, and reconciling the conflicting results obtained in estimating this value by different methods.

#### Quantitative Results of Degradation Estimates

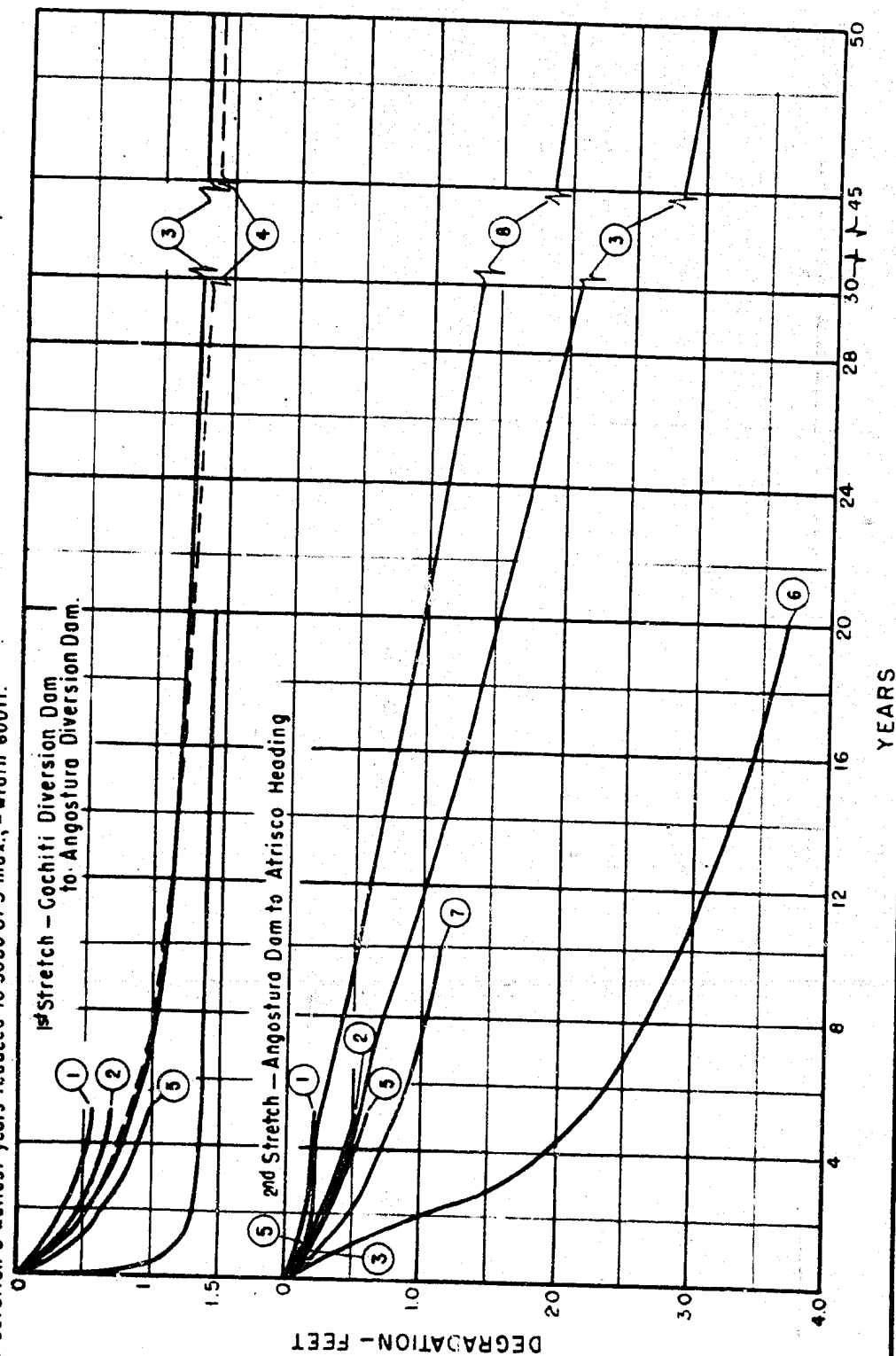
15. The quantitative results of the estimates of degradation are given on Figures 1 and 2. Figure 1 shows the estimated effect of the reservoirs operated to reduce flood peaks to 5,000 cfs with the channel below the dams restricted to a 600-foot width, and no sediment storage along the channel. The depth to which the bed material is assumed to be turned over is 2 feet in the first stretch, Cochiti to Angostura Dam and 7 feet below that point. The method of making these computations is given in detail in Appendix 1.

16. The results indicate a lowering of about 1.3 feet in the first 15 years in the stretch from Cochiti to Angostura, but little change for the next 35 years or to the end of the period studied. In the stretch from Angostura to Atrisco Heading, the lowering would continue for more than 50 years, reaching 1.5 feet in 20 years and 3.0 feet in 50 years. In the stretch from Atrisco Heading to Isleta Dam the degradation reaches 0.8 feet in about 5 years, after which it aggrades back practically to zero again at the end of 50 years. In the stretch from Isleta Dam to San Juan Heading it degrades about 0.6 feet in the first 5 years, but after that aggrades to about 1.3 feet higher than the elevation at the start at the end of 50 years. In the reach from San Juan Heading to the Rio Puerco it would degrade 0.6 feet in the first 10 years, after which it remains practically constant for 10 years and then starts to degrade again, reaching 0.8 feet at the end of 50 years.



# MIDDLE RIO GRANDE DEGRADATION STUDIES DATA USED IN DEGRADATION COMPUTATIONS

- ① Normal flow duration—natural width.
- ② Flow duration 3 driest years reduced to 5000 CFS max.,—width 600 ft.
- ③ Normal flow duration reduced to 5000 CFS max.,—width 600 ft.
- ④ Normal flow duration reduced to 7500 CFS max.,—width 600 ft.
- ⑤ Flow duration 3 wettest years reduced to 5000 CFS max.,—width 600 ft.
- ⑥ Normal flow duration reduced to 5000 CFS max.,—width 600 ft, degradation by sediment rating curves (suspended load data).
- ⑦ Same as ③ except using finer bed gradation of sediment.
- ⑧ Same as ③ except depth of turnover = 3.5 instead of 7.0 ft.



17. The computations indicated that the action was quite sensitive to particle size composition, and the assumption of slightly different bed size compositions would have produced considerably different results. Since the paucity of size analysis data of the bed material did not establish the true average size very conclusively, the computed values of degradation could not be positively established. Any change in the particle size, however, would have changed the amounts of degradation in the various sections with respect to each other, but would not change the total amount greatly. Although the results obtained are therefore not necessarily exact, the order of magnitude of the degradation is believed to be correct. Since the magnitude of the degradations computed are generally quite small, it therefore can be concluded that the degradation which would result with the confined channel downstream will be too small to be of much value.

18. In computing the amount of degradation certain assumptions were made which were necessarily somewhat arbitrary. The effect of different assumptions was therefore investigated. The flow each year was assumed to be equal to the average flow. The degradation which would occur if the first five years were the same as that of the five driest consecutive years, was determined. This is shown on Curve No. 2 of Figure 2. A comparison of this curve with Curve No. 3, which is the curve for average flows, shows that the degradation, although smaller, is only slightly less than for average flows. Similarly, the five wettest years would produce only slightly more than the average degradation, as shown by Curve No. 5. The effect of a change in the particle size used is shown by Curve No. 7. This curve shows the computed degradation for a bed material finer than the size indicated by the borings as shown on Table 1.

19. The degradation computations, in general, were based on the average annual transporting capacity of the stream for coarse load, which was estimated to be 2,350,000 tons per year. The average annual sediment load computed from a sediment rating curve for coarse load and an average flow duration curve was found to be about 9,000,000 tons. It is probable that the measurements on which this rating curve were based were taken at a narrow section during a time when the river was deepening this section and when it was therefore transporting more material than under average conditions. It is believed, however, that the 2,350,000 tons is a much more reliable value. However, the degradation which would result if the 9,000,000 tons were correct was computed and shown by Curves No. 6. This shows that materially greater degradation would result if the transporting capacity of the river was greater. The effect of increasing the value of the peak discharge to 7,500 cfs was also studied, as shown by Curve No. 4. In the first stretch this differed very little from the 5,000 cfs value as shown by Curve No. 3. Although the 7,500 cfs flow will carry materially more sediment than the 5,000 cfs flow, these flows occur only a small part of the total time, and the effect of varying them is therefore not great. Also, the effect of the greater peak flow is largely offset by the shorter length of time it flows. In these computations, however, the depth of turnover of the bottom material was assumed to be the same. Since the depth for the higher peak flow would probably be greater, the degradation rate for the higher peak discharge would be relatively greater than these studies indicated.

Table 1

"Comparison of Size of Bed Material with Assumed Finer Bed Material"  
 Reach No. 2--Angostura Dam--Atrisco Heading  
 Percent in each Fraction

	Finer:	Very fine:	Fine:	Medium:	Coarse:	Very:	Very:	Fine:	Medium:
	than:	sand:	sand:	sand:	sand:	coarse:	fine:	gravel:	gravel:
	0.062-	0.062-	0.125-	0.250-	0.500-	1.00-	2.00-	4.00	8.00
	mm:	mm:	mm:	mm:	mm:	mm:	mm:	mm:	mm:
Bed	:	:	:	:	:	:	:	:	:
material	:	:	:	:	:	:	:	:	:
from	:	:	:	:	:	:	:	:	:
borings	1.14	4.9	31.0	42.8	13.1	3.2	1.6	1.4	0.6
Assumed	:	:	:	:	:	:	:	:	:
finer	:	:	:	:	:	:	:	:	:
material	1.5	15.0	59.5	20.0	2.8	0.4	0.1	0.4	0.3
									0.169

### Possibilities of Increasing the Degradation Rate

20. As previously stated, the degradation rate will be small if all the sediment is carried to the lower end of the channel, and to attain a larger rate it will be necessary to store the coarse sediment at predetermined points along the stream. The amount of degradation will depend largely upon the number of times the same water can be induced to pick up a load of sediment from the bed and deposit it outside the channel. The portions of the present channel not used in the contracted section can be used for depositing the excavated sediment, and possibly wastelands can be utilized for this purpose.

21. The best procedure for the sediment deposits to accomplish the degradation can best be worked out by Hydraulic Laboratory studies, supplemented by a limited amount of experimentation on the river itself. So far as possible, the procedure of overbank deposition should be combined with the contraction of the channel. A great many possible schemes might be used, and an extensive laboratory investigation will be necessary. Considerable work of value along these lines has been done in India. Observations recently made on rivers in this country indicate that considerable progress can be made along this line. Most engineering progress is made by finding out the laws of nature and then setting up the conditions in such a way that nature will work to accomplish the desired end. The work on accelerated channel degradation would be conducted by working out the conditions which would best facilitate the action of the river in moving the sediment from its channel into the deposition areas.

22. A substantial advantage of the method of producing degradation by deposition along the channel is that much of the degraded material will be kept out of the Elephant Butte Reservoir, and the capacity of that reservoir will be kept available for water storage to this extent.

23. Another possible method of increasing the degradation rate would be to locate the channel where the size of sediment was small. To do this it would be necessary to determine by means of borings and size analysis, the parts of the area between the levees where the size of bed material was small and run the contracted channel through these portions. Whether or not this method is practical could only be determined by further investigation, which should be made.

### Effect of Water Temperature on Degradation Rate

24. Sediment measurements on the Lower Colorado River show that for the same discharge this stream carries much more sediment in winter than in summer. The cause of this is not definitely established, but the most likely explanation seems to be that it is a temperature effect. If it can be definitely established that this is the case, the temperature of the water may have an important effect on the rate of degradation. A search for temperature data on the Rio Grande water failed to locate any information except for that obtained with recent sediment measurements. In order to determine what the cause of the variation in sediment carrying

capacity of the Colorado River, the relation of this capacity to the temperature was studied in some detail. Appendix III gives the results of this study.

#### Limit of Degradation

25. Some engineers who have studied the degradation possibilities in the Middle Rio Grande have been concerned with the possibility that the degradation might be so great as to bring very disadvantageous effects, such as the undermining of bridges and dams. The studies previously discussed indicate that the principal difficulty will be in securing adequate lowering rather than from excessive lowering. The presence of gravel strata, as shown by the borings, indicate the limit to which degradation could be expected to go, even under much more favorable conditions for degradation than actually exist. These depths vary from about 7 feet at San Felipe to 10 feet at Albuquerque and to 15 feet at Lemat. These are the distances down from the present surface, and the depth below the bed of the river before the recent rapid aggradation is therefore considerably less than these values. Should degradation become excessive, the lowering could be greatly reduced by allowing the river to return to its natural width by ceasing to maintain the contraction works or by passing down the river some of the sediment entering the sedimentation basins.

#### Further Data and Studies Required to Perfect Estimates of Degradation Rates

26. The estimates of future rates of degradation reached by this study were considerably lessened in probable accuracy by lack of sufficient data on the mechanical analysis of the riverbed materials, both on the surface and below it. A great deal of mechanical analysis work has been done by the Soil Conservation Service, but this was done for the determination of the relative sediment contributions of the various parts of the drainage basin by the heavy mineral analysis method and in the selection of samples only sands were taken, the coarser and finer materials being avoided as unsuitable for this purpose. To make an estimate of degradation rate of a satisfactory degree of accuracy it will be necessary to get a systematic set of bed samples covering the entire length of the middle river. The samples probably should be taken on a grid system with points sufficiently closely spaced to give accurately the average bed composition.

27. The borings made by the United States Engineer Department as part of the cooperative program are practically the only information showing quantitatively the composition of the material an appreciable distance below the surface. This material was very valuable in this study but the borings were insufficient in number to insure an accurate average of the subsurface compositions. Many more similar borings with mechanical analysis of the material at different depths will be necessary to insure sufficient accuracy. These borings should also be made on a grid system. A limited number of bed surface samples and borings should also be made in the tributaries just upstream from their mouths, in order to give as reliably as possible the composition of the load brought to the river by these streams. It is believed that a boring rig, mounted in a truck could advantageously be used for the

borings required. It is understood that the army has developed equipment for this purpose for constructing military telephone lines.

28. As discussed in Appendix II, more information on the depth and width of the bed material which is moved by the high stream flows is necessary. For this purpose an analysis should be made of records of bottom scour obtained by current meter measurements in the Rio Grande and similar rivers. A large number of borings should be made in the river channel and the holes should be refilled with colored sand. These should be made at both narrow and wide sections of the river. By later examination of these holes the depth to which they had been washed away would show the depth of bed movement. The borings made to determine the size composition of the bed could be used for this purpose.

29. For the purpose of securing data on the depth of bed scour and for checking the accuracy of the methods of estimating degradation rate used in this study, data on bed composition of the surface and subsurface of the Lower Colorado River should be secured. The rate of degradation should then be estimated and compared with observed rates.

30. To secure more information of the degradation which has resulted on other streams where the sediment load has been cut off by dams, data should be secured from as many cases as possible where this has taken place. A special study should be made in the Rio Grande below Elephant Butte Dam. By comparing these rates with bed material, slope and the flow causing them, a further check on the rates estimated would be secured. This information would also be of great value in the design of dams and other structures on many other of the streams under study by the Bureau of Reclamation.

31. The selection of a 600-foot channel width for the estimates of degradation rate in the regulated channel was a very arbitrary one and before a determination of a width is made, extensive studies should be made. The selection of the best form of bank-protection works for this channel could be materially aided by Hydraulic Laboratory studies.

#### Miscellaneous Suggestions

32. The filling up of the storage dams with sediment will necessitate the enlargement of the storage capacity from time to time. A postponement of the need of this additional capacity might be obtained by flushing out part of the sediment from the basins to depositing areas just downstream from the dams. As the reservoirs become partially full, the head necessary to flush out the sediment onto lands at levels above the present riverbed will become available without the storage of water in the basins. The feasibility of such a procedure should be studied, and if desirable, the outlets in the dams should be designed to accomplish it.

33. Under ordinary conditions the space which is filled with sediment will become useless for any other purpose. It would be possible, however, to utilize the part of this space between the grains of sand for storage of water, if drains and conduits were constructed before the deposits were

made, to collect the water and discharge it through the dam. Since these basins are expected to store only the coarse material, the effective voids should be a considerable part of the sediment volume and the water could be drained out by gravity. To a limited extent this space would also provide flood control storage. This sort of storage would have the advantage that it would be less subject to evaporation than ordinary storage, and thus might be particularly adapted to hold over storage.

#### Acknowledgements

34. The studies involved in preparing this report were made in cooperation with the staff of the Hydraulic Laboratory of the Division of Geology and Research. The work was largely carried on in the Special Studies Group by D. J. Hebert, E. J. Carlson, and O. S. Hanson. Acknowledgement is also made of the assistance of Thomas Maddock Jr., and W. M. Borland of the Hydrology Section, Branch of Project Planning.

## Appendix I

### DETAILS OF METHOD OF ESTIMATING DEGRADATION RATES

Experience with degradation on the Colorado River below Lake Mead has shown that the clear water flowing from the lake picks up material from the bed and carries it downstream, thereby lowering or degrading the river bed. The ability of the water to carry the fine particles of bed material is very much greater than its ability to carry the coarse particles. The water therefore picks up from the bed much more of the fine material than it does of coarse material. This proportion of fine to coarse material picked up is greater than the proportion of fine to coarse material of which the bed is composed. The result is that the fine material in the bed is removed faster than the coarse material and the bed material remaining, gradually becomes coarser. As it becomes coarser the ability of the river to remove bed material becomes less. Therefore, the rate of the removal of the bed decreases and a condition is approached where the amount of material becomes so small that the channel practically ceases to degrade. At this time stability can be said to be reached.

The experience on the Lower Colorado has been that this condition was reached in a comparatively few years. Although the conditions on the Middle Rio Grande River are not exactly the same as those on the Lower Colorado, the similarity is great enough to insure that an action of this kind will occur in the Rio Grande. Any method devised for estimating the degradation which will result from the construction of the proposed reservoirs will, therefore, have to take this action into account. So far as known, no such method has previously been developed and therefore, it was necessary to devise one. The lack of a completely developed science of sediment transportation and deposition, the paucity of quantitative data regarding the materials dealt with in the Rio Grande, together with an inadequate knowledge of the action of the river on the materials composing its bed, has made it necessary to make several assumptions and approximations in developing the method. The results obtained therefore, cannot be expected to be highly accurate but they are the best that can be devised at the present time, and it is believed that they do indicate the correct order of magnitude of the various effects and indicate the general character of the results which will be secured. They should be very helpful in pointing out the best method of carrying out the proposed plans and in showing what information is necessary to make more accurate quantitative estimates.

Since the degradation which will result from the proposed reservoirs will change with the passage of time and will vary in the different parts of the river, it was decided to make the computations of these effects by a step method, dividing the river up into sections and estimating the changes which would occur in each section during successive time periods of one to five years length, following the completion of the reservoirs.

Since the degradation in any section of the river depends upon the excess of the amount of sediment taken out of the section over that brought into



## Appendix I

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Since the degradation which will result from the proposed reservoirs will change with the passage of time and will vary in the different parts of the river, it was decided to make the computations of these effects by a step method, dividing the river up into sections and estimating the changes which would occur in each section during successive time periods of one to five years length, following the completion of the reservoirs.

Since the degradation in any section of the river depends upon the excess of the amount of sediment taken out of the section over that brought into

the section, it is necessary to know both the sediment inflow and outflow quantities in each section in each of the successive time periods used. The amount coming into the section is made up of the amount brought in from the section immediately upstream, and that which comes in from local inflow. The amount which goes out of the section is that which the river carries out plus that which is diverted into irrigation canals. The local inflow and diversions were estimated from the best sources of information available, as will be explained later. The main river sediment inflow to the upper of the sections into which the river was divided, was based on the estimate prepared in drawing up the general plan for the improvement of the Middle Rio Grande Valley. The main river sediment inflow for the sections below the upper one was taken as a computed sediment outflow of the section next upstream. It was, therefore, necessary to compute first the degradation and sediment outflow in the most upstream section for the successive time periods and then successively compute the effects in the section next downstream.

#### Division into Sections

The sections, or reaches, into which the Middle Rio Grande was divided, for the purposes of this study are shown in Table A, together with other pertinent data.

Table A  
DATA ON MIDDLE RIO GRANDE SECTIONS

Section:	From	To	Section:	Average	
No	Place	Place	length-:	natural	
			miles	width ft	Area sq ft
1	Cochiti	Angostura	22.19	1,050 ft	123,000,000
2	Angostura	Atrisco	25.76	1,200 ft	163,000,000
3	Atrisco	Isleta	13.90	1,350 ft	99,000,000
4	Isleta	San Juan	24.46	1,050 ft	136,000,000
5	San Juan	Rio Puerco	14.94	950 ft	75,000,000

#### Local Sediment Inflow and Diversions

The sediment inflow which occurs locally in the various sections was taken from the estimate prepared in the sedimentation appendix of the plan for development of the Middle Rio Grande. The amounts and compositions were taken from the estimate made for the general design of the Middle Rio

1/Numbers refer to references at end of this report.

Grande Project previously mentioned. The size composition of this sediment was taken from sediment measurements made during summer flood flows in the Rio Grande, since most of the local inflow comes during such periods. The amount and composition of coarse sediment taken out of the river with the irrigation water was estimated from the amount of water diverted and the coarse sediment concentration and composition in the water at that point. It was assumed that the canal headgate was manipulated to reduce the sediment to a minimum and, therefore, that the sediment concentration of the water diverted was half that in the river.

#### Duration of Main River Flow

The duration of flows of various magnitudes which will exist after the construction of the flood control dams will differ considerably from that which has existed in the past. It is expected that the maximum flow which will be permitted to pass down the river at the upper end of the Middle Valley will be 5,000 cfs. Occasional local inflows will bring the channel flows above this amount, but their duration will be very short, and the amount of water involved will be small.

Since studies of the operation of the reservoirs was not available, their effect on the duration was estimated by adjusting the shape of the curve to reduce the maximum flow to 5,000 cfs and increase the duration of flows just below 5,000 cfs to provide the same total quantity of flow as in the unregulated condition. It was assumed that most of the flow above 5,000 cfs which was stored would be released soon after the natural flow had fallen below 5,000 cfs.

#### Main River Sediment Inflows and Outflows

As previously stated, the amount of sediment carried by the river into the upper end of the Middle Rio Grande channel was based on the estimate of the amount of sediment carried by the river in its present form, as determined in the general plans for the Middle Rio Grande Project. This estimate was based on a complete study of the weights of sediment brought in by the main river and by the tributaries and the measured disposition of it in the aggradation of the valley floor and the deposits in the Elephant Butte Reservoir. It was assumed that the amount of wash load (which would include all of the material of silt and clay size) would not be changed by the construction of the dams, but that it would all pass without deposit, through the contracted channel which it is proposed to build. It was assumed that the flood-sediment control reservoirs would be so manipulated that all of the material of sand sizes reaching them would be deposited therein. The small quantity of sediment which would come down the Upper Rio Grande or be removed from the coarse deposits in the river channel between the mouth of the Chama River and Cochiti Dam was assumed to be negligible and the flow of coarse sediment at Cochiti was therefore neglected.

The estimate of sediment carried by the Middle Rio Grande under present conditions, previously mentioned, showed that the various stretches of the

river between Cochiti and the mouth of the Rio Puerco carried an average of about 2,350,000 tons of coarse material per year. Coarse material being that part of the sediment composed of particles of sand and larger sizes or larger than 0.0625 mm. This quantity is for the present river conditions of unregulated flows and natural river widths.

The reduction of the peak flows by the reservoirs will tend to reduce the ability of the river to carry coarse sediment but the confinement of the streambed below the dams will tend to increase it. The magnitude of the effect of these two opposing trends was estimated by computing, by means of sediment transportation formulas, the average annual amount of sediment carried by the unregulated, natural width stream and also by the regulated, confined width stream. To get the capacity of the stream after the changes are made, the present capacity of the stream, 2,350,000 tons per year, was multiplied by the ratio of the computed capacity of the regulated, confined width stream to the computed capacity stream in its present condition. The results of these computations are shown below.

COMPUTED TOTAL SEDIMENT LOAD IN FIRST  
STRETCH FOR DIFFERENT CONDITIONS

	Total load <u>T/year</u>
Width = 1,050 ft--Flow duration normal (21,600 cfs maximum)	1,392,389
Width = 600 ft--Flow duration normal (21,600 cfs maximum)	1,714,037
Width = 1,050 ft--Flow duration reduced to 5,000 cfs maximum	1,080,458
Width = 600 ft--Flow duration reduced to 5,000 cfs maximum	1,606,329

This shows that the effect of narrowing the river channel to 600 feet was greater than the reduction of peak discharge to 5,000 cfs, and therefore that the initial effect of the improvement was to somewhat increase the rate of transport of sediment by the stream.

It will no doubt be noticed that it would be possible to use the computed quantity carried under the new set of conditions instead of that obtained by the previously described method. Because of the lack of accurate knowledge of the size composition of the bed material and the temperature of the water and because our knowledge of the fundamental theory of sediment transportation is inexact, it is believed that more accurate results would be secured by the method adopted. This uses the theory to compute only the relative effect of the changes due to the proposed plan and to depend upon measured quantities to give the rate for present conditions. Both the temperature and the size of bed material have a large effect on the amount of sediment transported, as computed by

the formulae used, and therefore the results obtained by these formulae with the approximate values which it was necessary to assume for these quantities, was apt to be considerably in error. The estimate of material carried under present conditions however, although subject to some uncertainty, was believed to be much less subject to error. Therefore, it was believed that a method which would use this value for the basic quantity, and modify it by computation, where computation was necessary, would give a more accurate result than to use computation for the entire process.

When these studies were started, it was expected to use, as the transporting capacity of the river for coarse sediment, the amount of this material for various discharges shown by the results of sediment sampling observations in the river channel. For this purpose sediment rating curves at various points where data were available were drawn up, but when these curves were applied to the duration curve of mean annual flow they gave mean annual sediment discharges several times the 2,350,000 tons estimated from measured volumes of deposited material. Since it is believed that any error in the 2,350,000-ton value is much less than this would indicate, it was concluded that the use of these rating curves was not desirable.

The reason why the transportation of sediment in suspension as determined from sediment samples appeared to be so much larger than that obtained from measured deposits is not apparent, but it is probably related to the problems discussed in Appendix II.

#### Composition of the Bed Material

The estimate of degradation is based on an initial composition of the riverbed material, which was taken to be that existing in the bed at the present time, as nearly as could be determined from the few borings which were available. The composition of the bed in each section of the river was determined from the size analyses made from the samples taken from the borings made in that section, down to the depth which was assumed to be the lowest level at which the flowing water would turn over the bed material. Since the number of borings in the river channel in one section were only from 2 to 6, the composition of the bed material was not established very accurately.

#### Depth of Turnover

As discussed in Appendix II, the depth to which the bed material in a stream is worked over by the flowing water has an important effect on the rate at which it will degrade, but little is known in a quantitative way about this matter, and the available data are conflicting. In these studies sufficient data to obtain reliable values of this depth were not available and more or less arbitrary values had to be assumed. In the stretch between Cochiti and the Angostura Dam, the bed is composed of coarse material and it is believed that the depth which would be worked over by the 5,000 cfs maximum flows would be small. In this stretch the depth was therefore taken as 2 feet. Below Angostura Dam the riverbed is

composed of much finer material, and the depth of turnover is expected to be greater. The borings indicate that the bottom becomes appreciably coarser at a depth of about 7 feet and this depth of turnover was, therefore, assumed in this stretch for the river between Angostura Diversion Dam and the mouth of the Rio Puerco. A study was also made of the effect in some sections for a depth of 3-1/2 feet. Although most of the high flows in the river will be eliminated by the reservoirs, occasional flows of considerable magnitude will come in from the tributaries which will assist in working over the bed material in this part of the river. The effect on the results obtained of errors in estimating the depth of this turnover is discussed later in this appendix.

#### Details of Estimate of Degradation for the First Year

In the estimate of the degradation for the first year a trial computation was first made, in which the initial rate of degradation of the various sizes was assumed to hold during the entire year. From the amount of material, which this assumption gave as being carried away from the zone of material which was worked over by the stream, or what may be called the "turnover zone," the average change of composition of this zone during the year was computed. The average of the composition at the beginning and end of the year was then taken as the bed composition and a revised estimate was made of the weight of material carried by the stream during the year and the degradation which this would produce. This value of lowering was taken as the degradation caused by the dams for the first year. The composition of the turnover zone at the end of the year was also estimated with this revised rate of movement out of the zone, and this composition was taken as the initial rate for the second year.

The order of the steps in the computation of degradation for the first year in any reach of the river was as follows:

- (1) Determine the initial composition of the bed material in each reach from the borings in that reach.
- (2) Compute the mean annual discharge capacity of the stream channel for sediment by means of formulae, for its natural width with unregulated flow and for the contracted channel with regulated flow.
- (3) Adjust the contracted regulated flow discharge to agree with observed discharge with natural width and unregulated flow.
- (4) Compute the amount of each size range of material carried out of the section. Then compute the change of bed composition during the first year due to the combination of this sediment outflow, the sediment inflow from the section next upstream, the local sediment inflow, and the sediment carried out by the irrigation water.
- (5) Determine the average bed composition during the year.



(6) With this average bed composition repeat Step 4 to get the net amount of material removed from the section, and thus the amount of degradation or aggradation.

(7) Compute the depth remaining in the turnover zone at the end of the year and the degradation during the year, also the bed composition at the end of the year, which will be used to compute the degradation the next year. The degradation for the next period was computed by repeating steps 4 to 7 inclusive.

The following paragraphs give more details on how the computations in each of these steps were made.

Step 1.--The initial composition of the material in the turnover zone in each reach was determined from the average composition as shown by the borings taken in the river channel, for the depth which would be turned over, as previously stated. The results of the borings outside the channel were not included. The size composition was divided into parts, according to the American Geophysical Union <sup>2</sup>/classification, and the percent of the total weight in each size range was determined. Assuming that each class of material accounted for a depth of material proportional to its weight, the depth in each size range in the turnover zone was computed.

Step 2.--The rate at which material in each AGU size range could be transported at the beginning of the first year was computed by formulae, for the present condition of the river, with its natural width and unregulated flow and with the proposed narrow width and regulated flow. The transportation rate for the suspended load was computed by the Lane-Kalinske relations <sup>3</sup>/and for the bed load the average of the Kalinske<sup>4</sup> and Schoklitsch <sup>5</sup>/formulae were used. The total load was taken as the sum of this suspended load and the average of the two estimates of bed load. The Einstein bed (material) load formula was not used, since the sizes involved were too small for accurate determination by this formula. The Straub formula was found to give quantities obviously considerably too large. The flow conditions in the natural channel were computed using the natural width and Manning's formula with a value of "n" of 0.025, which is an average value based on measurements and computations of the U. S. Army Engineers. The slope of the stream was taken from the river profile and the unimproved width was taken from the best available maps. For the controlled channel a width of 600 feet was used. The amount of material transported in suspension was computed by the Lane-Kalinske relations, assuming there was only one percent of that size in the bed and the bed load by the Schoklitsch formula was computed for each size range, assuming that the entire bed was composed of that size of material. The amount carried was taken as the average for the various sizes weighted according to the percents by weight which each size fraction composed of the bed material determined from the borings. The amounts transported by the Kalinske formula were weighted according to the area which each size range covered in the bed, as explained in the article <sup>4</sup>/describing that formula.

The amounts of bed and suspended load carried of each size fraction was computed for both present channel conditions and the contracted channel for a number of discharges within the range of discharges, as shown by the flow-duration curves. Sediment rating curves for each size fraction were prepared showing theoretical relation of sediment discharge to water discharge under these two conditions. The mean annual theoretical sediment discharge for the present condition of the stream was then computed by applying the values indicated by the rating curves for this condition to the discharges under present conditions as indicated by the flow-duration curves. The total quantity was taken as the sum of the amounts for the various size fractions. The mean annual theoretical sediment discharge for the contracted channel and regulated flow was similarly computed by combining the values from the sediment load rating curves of the contracted channel with the values from the flow-duration curve of regulated flow.

Step 3.--The third step was to adjust the theoretical computed carrying capacity for the contracted channel to agree with the observed carrying capacity of the natural channel. This was done by assuming that the theoretical computed values for both present and future conditions were in error by the same percents. The correction of the theoretical capacity for the contracted channel was made by multiplying it by the ratio of the observed value for present conditions (2,350,000 tons per year) to the computed theoretical value for present conditions. From the average annual amount carried, as thus computed, the equivalent depth over the stream bed was computed for each section into which the river was divided. A density of 100 pounds per cubic-foot, as determined by Happ <sup>6</sup> was used in this estimate. This was divided into depths of bed and suspended load by assuming that the average of the two computed bed loads was correct and the remainder was suspended load. This was done because it was believed that the average of the bed-load formulae probably gave a more accurate value than the suspended-load formula. The depths of bed and suspended load were then divided to give the depths in each of the size fractions. For the bed load, this was done by assuming that size distribution was the same as in the average size distribution computed by the two bed-load formulae for the regulated flow and contracted width. The size distribution for the suspended load was assumed to be the same as computed suspended load for the same condition.

Step 4.--The depth in each size range carried out of the reach was the adjusted depths computed in the previous step, if a sufficient depth of material of that size was available in the turnover zone. If the depth was insufficient, the total amount available was carried out. The local inflow of sediment in each size range, in terms of depth over the stretch was next computed, and a similar computation was made of the depth for each size for the sediment carried away by the irrigation water. The concentration of sediment carried away by the irrigation water was assumed to be half that of the computed suspended load in the contracted channel for the next stretch upstream. This reduction of the concentration of suspended load was made to take care of the effect of



sluicing at the headworks of the irrigation canals. The change of bed composition during the year was then estimated by computing the depth of each size range remaining in the turnover zone at the end of the year, assuming that the initial rate of movement continued throughout the year. For each size range this depth was the initial depth in the turnover zone, plus the depth brought in by the outflow from the reach next upstream, plus the depth brought in by local inflow, minus the depth carried out by the irrigation water, minus the depth carried out at the lower end of the reach.

Step 5.--The average bed composition during the first year was next computed by assuming that it was the average of the initial composition and the final composition as computed above.

Step 6.--A revised computation of the depth of material transported in the contracted channel was next made by repeating the latter part of Step 4, using this average bed composition. To facilitate this and subsequent computations, a diagram, as shown in the sample computations, was drawn up, showing the depth transported (if available) in each size range for each percent of that size in the turnover zone. This was done by plotting on Cartesian or ordinary coordinates for each size, the depth transported in the contracted channel, as determined in Step 2, against the initial percentage in the turnover zone. Straight lines were then drawn through the origin of coordinates and through these points. These lines indicate the depths transported for all other bed compositions, assuming that the amount transported is proportional to the percentage of the size in the bed.

Step 7.--The amount of degradation was next computed by subtracting from the total of the depths of the various size fractions in the turnover zone at the beginning of the period, the total of the depths of these size fractions at the end of the period. From the depths of the various sizes at the end of the period, the initial composition for the next time period was computed. The depth of the turnover zone was assumed to decrease by the amount of material removed by the degradation, no new material being taken in at the bottom of the zone as the degradation continued.

#### Effect of Various Assumptions

In working out the method used for estimating the degradation rate, it was necessary to make a number of assumptions. Some of the assumptions were made because of lack of information on the true action, and some were made in order to get the computation simple enough to be practicable to compute. Some of these assumptions probably depart somewhat from the true situation. In the following, the probable result of these departures is considered.

The assumption that the inflow of sediment at Cochiti is negligible, is too favorable to high degradation rates, but the amount is very small, and therefore the error involved is also small.

The assumption of a turnover depth of 7 feet in most of the sections may be greater than the true amount for maximum flows of 5,000 cfs. So little data on this point are available that it was not possible to make accurate estimates. If the depths of turnover were less than 7 feet, the estimates of degradation would tend to be too large, as shown by the results for a 3-1/2-foot turnover.

The assumption that the material on the surface of the bed was composed of material of the average composition of the turnover zone probably gives too high a composition of fine sizes in the bed and thus tends to give too great values of material carried out of the bed.

The assumption that the removal of material lowers the bed in proportion to the weight removed probably results in too large degradation values, since the removal of the fines probably increases the voids and thus decreases the density of the material, and hence does not decrease the volume as fast as the weight is decreased.

The assumption that all of the silt and clay sizes are removed the first year is probably somewhat too favorable, but this material probably is removed in a comparatively few years.

The seepage of water from the channel and its return at points farther downstream as drainage water tends to slightly reduce the degradation from the values computed.

The assumption that all of the material degraded from the bed is carried to the downstream end of the most downstream section without deposit tends toward too low an estimate of degradation, since for any practicable method of controlling the stream width some sediment would escape from the channel and be deposited, and the clarified water would return to the channel again.

All of these assumptions except the last tend toward producing greater degradation rates than the true rate, and the resulting rate is, therefore, probably too large in the upstream sections. However, the estimation of too high a rate in the upstream sections results in too low an estimate for the sections farther downstream, and the total lowering is probably not far different from the true values.

## Appendix II

### DEPTH OF RIVERBED SCOUR DURING FLOODS

One of the uncertainties in estimating the rate of degradation which will take place below the sediment storage dams proposed in the Middle Rio Grande Valley is the depth of the riverbed material which is moved by the river during high flows. As discussed elsewhere in this report, it is expected that the clear water released from the reservoirs will pick up material from the bed of the stream downstream from the dams and carry it on down the river, causing the riverbed to be lowered because of the removal of this transported material from it. Observations below Hoover Dam indicate that the flow will carry away a larger proportion of the finer particles in the bed than it will carry of the coarser particles, with the result that the particle size composition of the bed material will gradually become coarser. For example, Figure 1 shows the increase in size of the bed material at Section 8, a short distance below Hoover Dam. Since a given river flow can carry a lesser volume of coarse material than it can carry of fine material, this coarsening of the bed will cause the river to carry away a continually smaller amount of material as time goes on and the coarsening proceeds and thus rapidly reduce the rate of degradation. After a certain period of time the lowering of the bed will be negligible. The rate at which the fine sand is removed and the length of time before the degradation rate becomes negligible depends upon the depth to which the riverbed is scoured during high flows, since the amount of fine material which can be removed by the river depends upon the depth of the material which comes in contact with the flowing water and thus can be carried away. If the depth of scour is small, only a little fine material can be carried away before the bed becomes covered with coarse material, but if the depth is great, a large amount will be carried away before the bottom becomes too coarse. The removal of the small amount in the case of the small depth of scour will lower the bed much less than the removal of the large amount if the depth of scour is great.

#### Conditions on the Rio Grande

The Middle Rio Grande is a steep stream and carries a heavy sediment load. It is wide, shallow, and relatively straight. The channel is frequently divided by islands, or takes what is known as a braided pattern, although it is very wide and shallow in some stretches and narrow and deeper in other stretches. In many respects it resembles numerous other rivers found in the Western United States.

Over the past forty years, the discharges of the Rio Grande and other similar rivers in the western states have been determined thousands of times in high and low water conditions. In each of these measurements the cross-section was determined by frequent soundings across the stream bed. It has generally been observed at these measurement sections that as the flow of water in the stream increases, the depth of the flowing water increases more than the water surface level rises. This indicates that

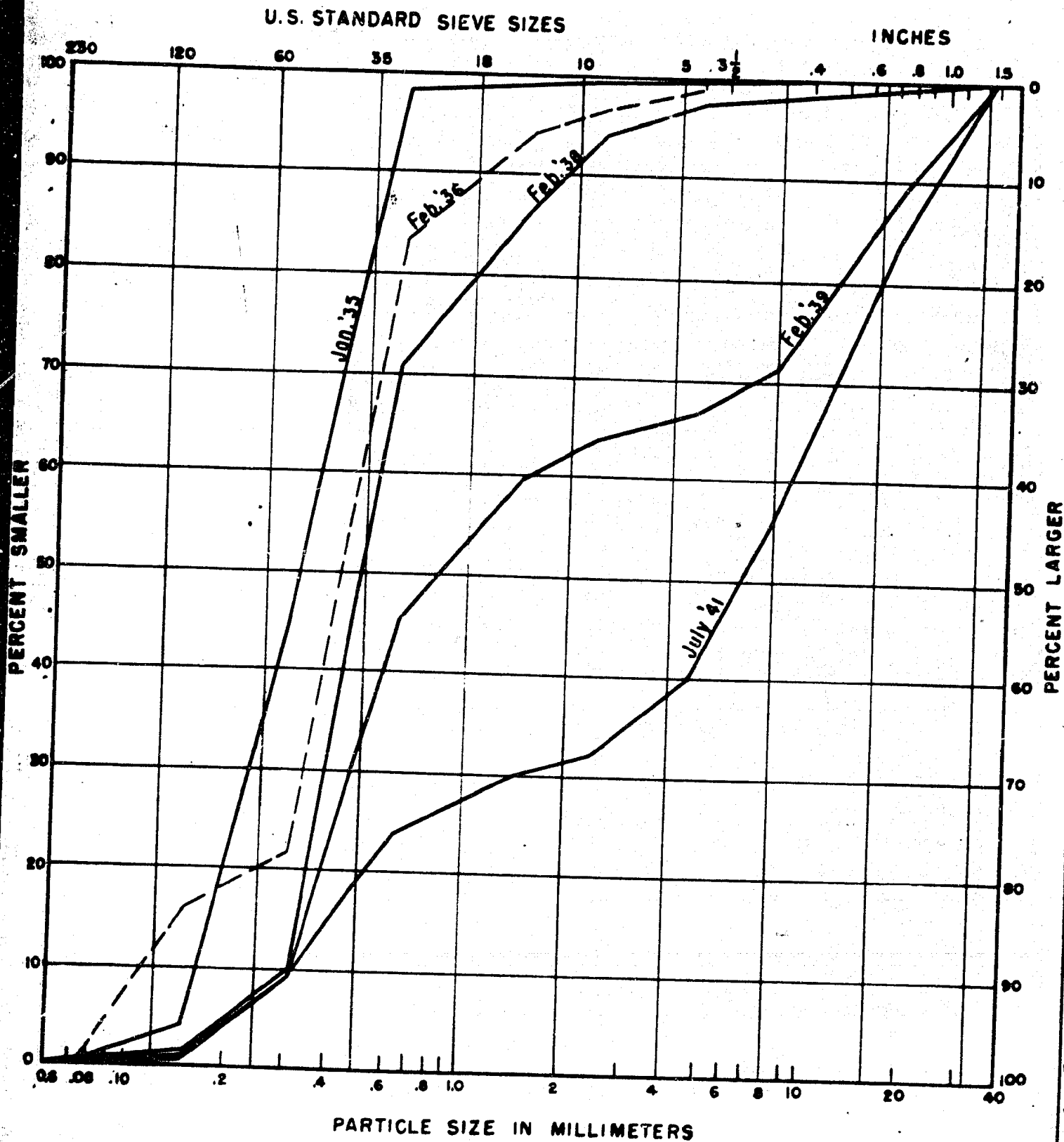


FIGURE 1  
COARSENING OF COLORADO RIVER BED  
BELOW LAKE MEAD

the bottom of the stream has been scoured out. It is not uncommon for the bottom to lower twice as much as the water surface rises. When the flood crest is passed and the flow decreases, the bottom begins to fill in, and when the flood has passed, the bottom has risen substantially back to the level which existed before the flood. This is shown by Figure 2 which gives the changes which took place in the riverbed at the San Marcial gaging station on the Rio Grande River during the year 1929. Similar changes have so frequently been observed in the Rio Grande and other rivers that it is the general impression of many experienced stream gaging men in the western states that this is a general action of the channel for streams of this type. They believe that when a flood comes the bed of the stream, at least for the greater part of its length and width, scours down materially, and refills as the flood recedes. This is an opinion widely held by men gaging the Rio Grande River, and it is reinforced by observations that piles 40 feet long driven with most of their length below the stream bottom are occasionally seen to rise suddenly in the water and float away, and bridges resting on 60-foot piles have been washed out during floods.

#### Conflicting Evidence

The evidence of the experienced stream gagers and other local observers seems quite conclusive, but when one starts to examine the situation quantitatively he runs into some surprising evidence which raises serious question as to the accuracy of this general impression. If the Rio Grande scours down several feet over substantially its entire width and length, it must move a very large quantity of material down the river. Practically all of the material transported by this stream is deposited in the Elephant Butte Reservoir. Frequent measurements have been made of the volume of sediment being deposited in this basin and the amount is known with reasonable accuracy. When we compare this amount with that which would have to be moved into the reservoir with an average depth of scour over the riverbed of a considerable depth, say 1.5 feet, we find that the amount actually deposited is very much less than would occur with this scour. We thus have the conflicting evidence of the scour observed by the stream gagers and the lack of a corresponding amount of material deposited in the reservoir.

In quantitative terms this conflict may be shown as follows: The section of the Rio Grande River from Cochiti to San Marcial has a length of 160 miles and an average width of 1,170 feet, giving it a surface area of 22,700 acres. For each foot of average depth of scour, assuming that the material scoured out moved as fast as the water, a volume of 22,700 acre-feet would, therefore, be carried into the lake. The average amount of material carried into the lake per year is 13,276 acre-feet, of which only about 1,828 acre-feet are composed of sand and larger sizes, such as would be scoured out of the stream bottom. Since floods sufficient to scour the riverbed occur practically every year, it is evident that the average depth of scour during floods, even if all the deposited coarse material

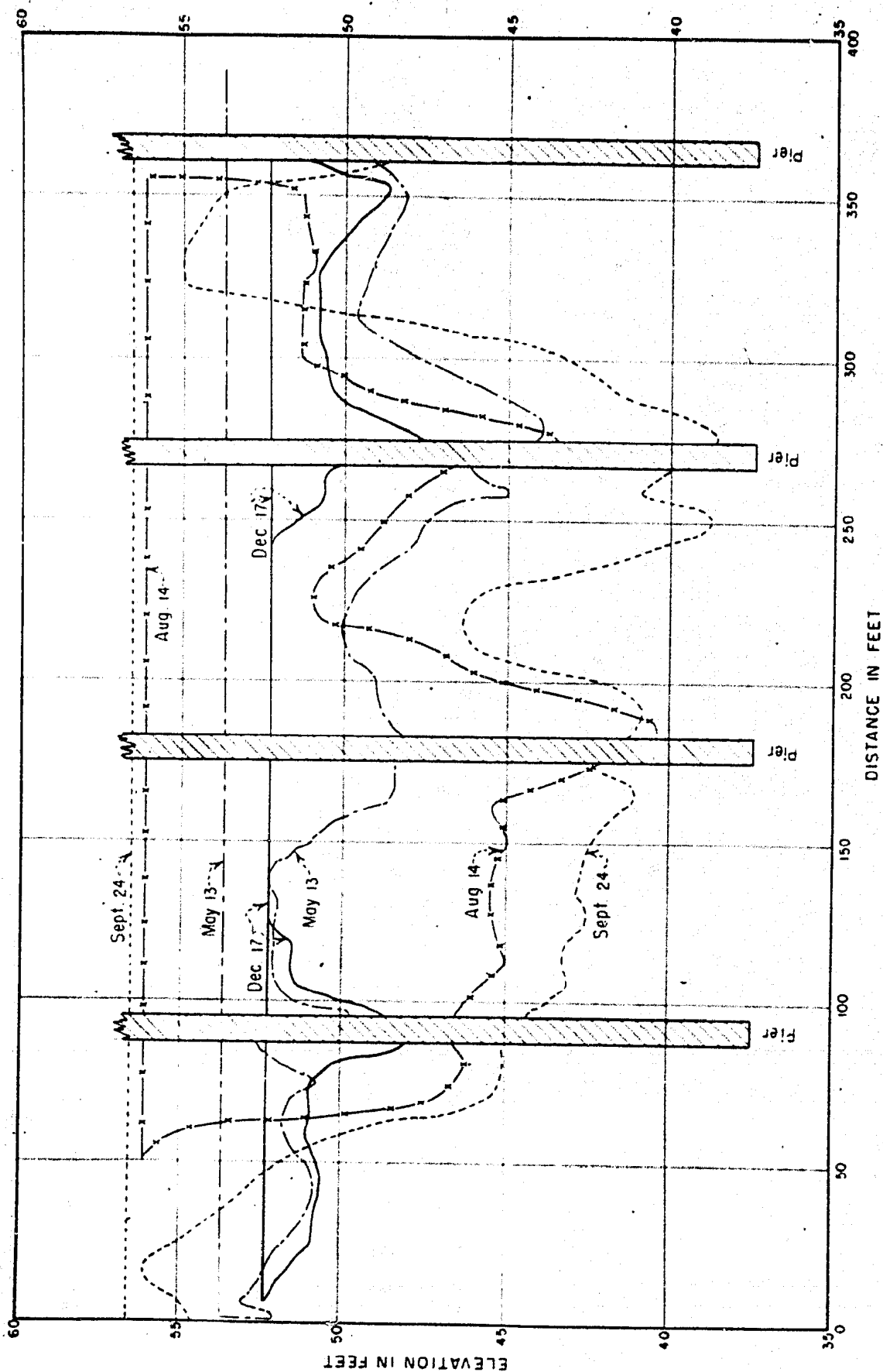


FIGURE 2  
CHANGES OF RIO GRANDE CROSS SECTION  
SAN MARCIAL, NEW MEXICO 1929

is assumed to be moved out of the bed, is only about 0.02 feet. If the much smaller annual loads carried into the lake above Elephant Butte Dam in recent years is used, instead of the long term average, the depth would be much smaller than 0.08 feet. It may be agreed that the solid material does not move as fast as the water, and this is no doubt true to a small extent. However, with the high concentrations which would be necessary for the transportation of the amount of material involved in the movement of considerable depths of scoured material, the resistance to the flow of the water as it passed between the slower moving particles of this material, would, if the solid material moved appreciably slower than the water, be so great that the slope of the river would not supply enough energy to accomplish it. Moreover, the particles could not long continue to move at much slower velocity than the water, except as they come in contact with the bed, since there is only their inertia to keep them from acquiring the same velocity of the water. Therefore, all the material except the small part of coarser particles which come in frequent contact with the bed, must move with substantially the same velocity as the water.

Another reason for questioning the existence of large depths of scour over substantially the whole of the stream-bed area is that the measurements of sediment concentration made in the river do not show sufficiently high values to account for so great a transportation of material. Below the mouth of the Rio Puerco the concentrations are high, due to the tremendous sediment load of this stream which is probably the carrier of the highest sediment concentration in the United States. To have a bed lowering of 15 feet in depth, over half of the channel area would require concentrations of the order of 50 percent by weight of solids for a discharge of 7,500 cfs. For a discharge of 20,000 cfs, the bed would lower 4.0 feet to produce the same concentration. Even below the mouth of the Puerco such concentrations have not been observed, and above the Puerco nothing approaching it has been observed.

#### Study of Evidence from Other Sources

Since the data available from the Rio Grande River were so conflicting that no satisfactory quantitative values could be obtained, it was decided to make a general study of the available literature bearing on this subject, with a view to obtaining more light on this point. The following is a summary of the principal information brought out by this investigation.

This study disclosed that very few measurements for the primary purpose of determining general bed scour have been made. Most of the data available have been secured from measurements made primarily for other purposes, such as from stream discharge or surveys to determine depths available for navigation. Observations of local scour, such as those at bridge piers or abutments, are of no value in determining the general bed scour with which this study is concerned. The available data seem to deal with two general classes of rivers, large rivers, of small or moderate slope, like the Mississippi and the Missouri, and smaller rivers of steep slope, such as one frequently finds in the Western United States. The

situation in these two types of streams differ somewhat. The larger rivers, if they flow in alluvial beds, consist of a series of bends, between which are stretches of more or less straight river. In the straight sections the main channel of the river usually crosses from one side of the river to the other, and the place where it does is called a crossing. At ordinary stages the bends are usually deep and relatively narrow and the crossings are wider and shallower.

In Figure 3 are shown diagrammatically (A) a typical cross-section of a large river at a bend and (B) a typical cross-section at a crossing. The water level at medium stages is represented by the lines b and b', and at high and low discharges by a and a' and c and c', respectively. At medium stages the cross-sectional area of flow is about the same in both cases and the velocity of flow is consequently also about the same. In floods the water level rises to a and a', a rise of approximately the same height above b and b'. Because the width in the crossing is considerably greater than in the bend, the rise of water level increases the cross-section in the crossing more than in the bend, and, therefore, makes the total cross-sectional area at the crossing greater than at the bend. This causes a lower velocity at the crossing than at the bend, and therefore tends to produce less scour in the crossing than in the bend. In low water the opposite action takes place. The areas in the bends become larger than in the crossings and more scour takes place on the crossings. In high water, then, the pools usually scour out and at the crossings deposit takes place, while during low water the crossings scour out and the bends fill up. This is a well-established phenomena in large alluvial rivers. Since the conditions in the Rio Grande differ considerably from those in the large rivers mentioned, it was not known to what extent this action also takes place in that stream.

#### Bed Scour in the Rio Grande

That the bed of the Rio Grande is lowered in time of floods, at least at certain points, is shown by the cross-sections shown on Figure 2. These represent the bed of the river under the Santa Fe Railroad Bridge at San Marcial in 1929. Some of the sections were taken during the large flood of that year. The stream is contracted to some extent here at high flows and the presence of bridge piers no doubt increases the scour, the tendency of the bed to be deeper near the piers being evident on the sections. These piers are set at an angle with the direction of flow, which no doubt increases somewhat their scouring effect.

During the release of water from the El Vado Reservoir, in November and December of 1946, frequent measurements were made of discharge and flow area at Bernalillo, Albuquerque, Belen, and Bernardo, on the main stem of the Rio Grande River, by the United States Geological Survey and U. S. Engineer Department. The discharge reached about 2,500 second-foot and considerable bed lowering was observed at each station. The maximum increase in area at these stations above the area when the



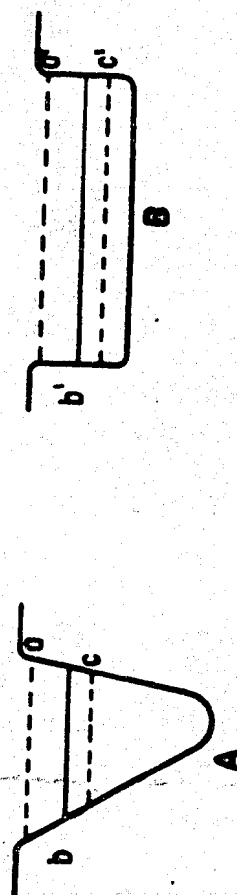


FIGURE 3  
TYPICAL CROSS SECTION OF A LARGE RIVER  
AT A BEND AND AT A CROSSING

release started was about 230, 340, 350, and 550 square feet, respectively. This increase in area did not follow consistently the increase or decrease in discharge. At the Bernalillo and Albuquerque stations it varied rapidly up and down with a nearly constant discharge, the range of these rapid fluctuations reaching as much as 150 square feet. The Albuquerque, Belen, and Bernardo measurements were made from bridges where the piers no doubt somewhat increased the scour and those at Bernalillo from a cableway. At this point the river is narrow and curves somewhat with a scour resisting bank on the outside of the curve.

Considerable data on the scour at stream-gaging stations on the Rio Grande could no doubt be obtained from a study of the soundings taken at discharge measurements on the river during floods. Time for this purpose was not available in making this study, but it is believed that such a study would be amply justified and would furnish much information of value.

#### Bed Scour on the Colorado River

Discharge measurements have been made on the Colorado River at Yuma, Arizona, since 1878. The large lowering of the bed which occurs at this station during floods has been widely known and has been partly responsible for the impression that the river bottom of such streams in floods scour deeply. Some of the flow cross-sections for the years 1912, 1916, and 1929 are shown on Figure 4. In general, the maximum increase in depth at the section is about twice the rise in the water surface. These measurements were made by a cableway at a very narrow section of the river, where one or both banks are of scour resisting material. The bed is of very fine sand.

In striking contrast with the large bed lowering at the Yuma station was the situation at the site of the Imperial Dam. A cable station was operated here for a short period before the dam was constructed. During this period the flow reached a maximum of about 65,000 second-feet. Although the bottom shifted considerably, being higher first on one side and then on the other, there was no appreciable change of the mean bottom level. This station was located about 6 miles above the Laguna Dam where a fixed masonry crest extended entirely across the river, and might exercise some influence on the cross-section at the measuring cable.

#### Other Examples of Bed Scour

On Figure 5 are shown cross-sections at two stations on the Yellow River in China described by J. R. Freeman (7), which show the lowering of the bed of this stream during a flood. These were taken at gaging stations where the river was probably narrow. At one of them, rock was exposed nearby on one bank. Cross-sections of the Verde River near Fort McDowell, Arizona, are given by F. N. Holmquist (8) which show a

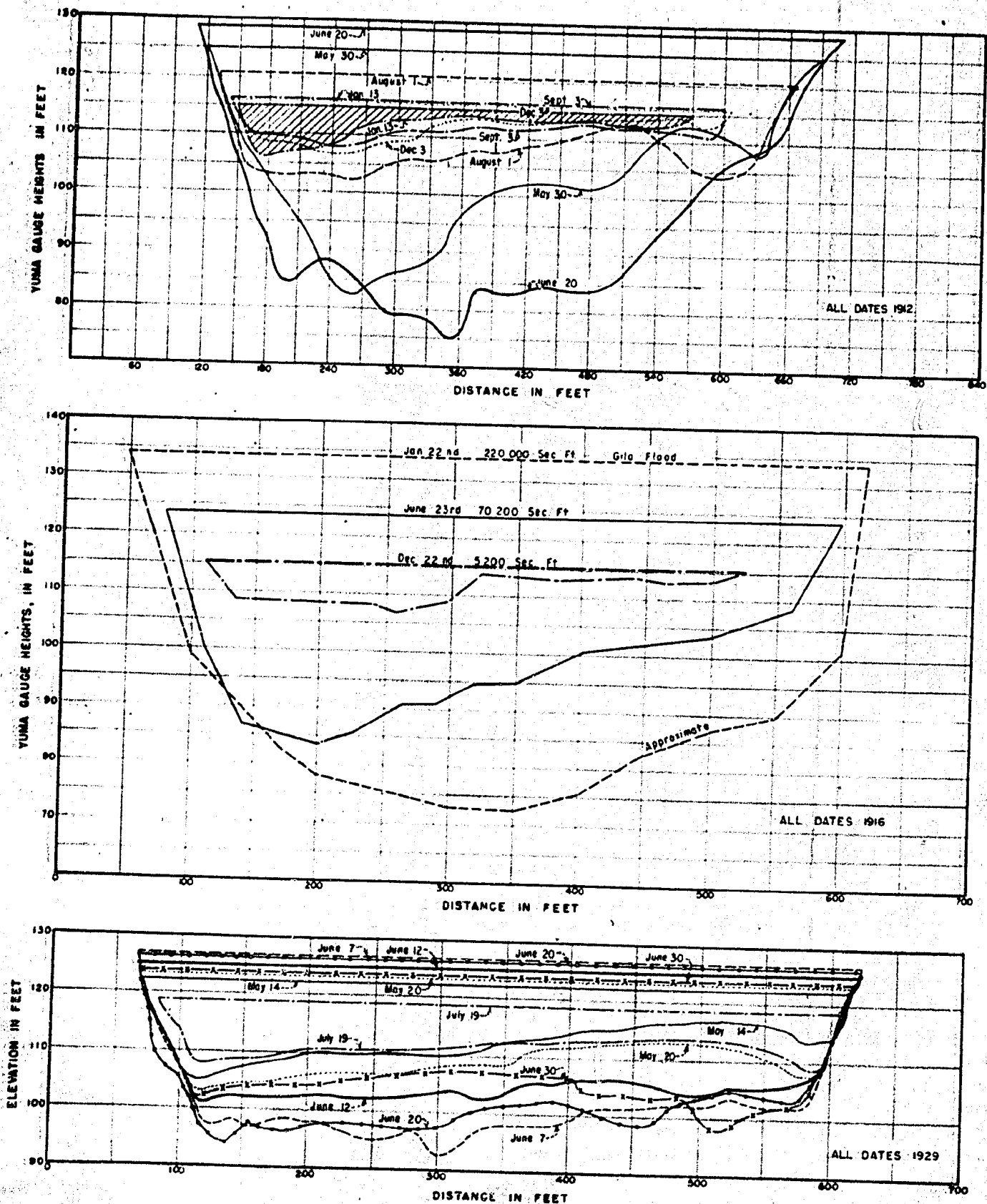
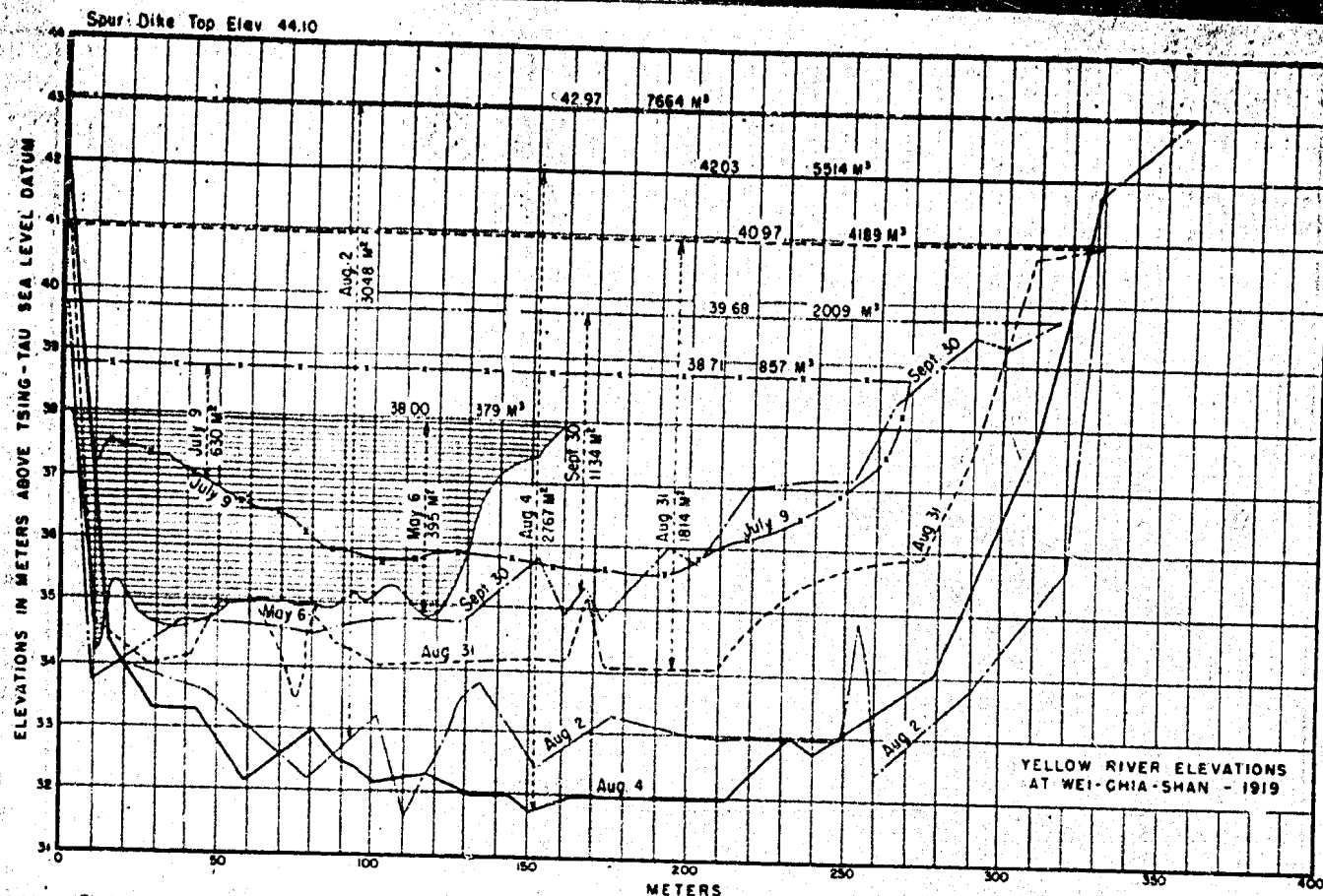
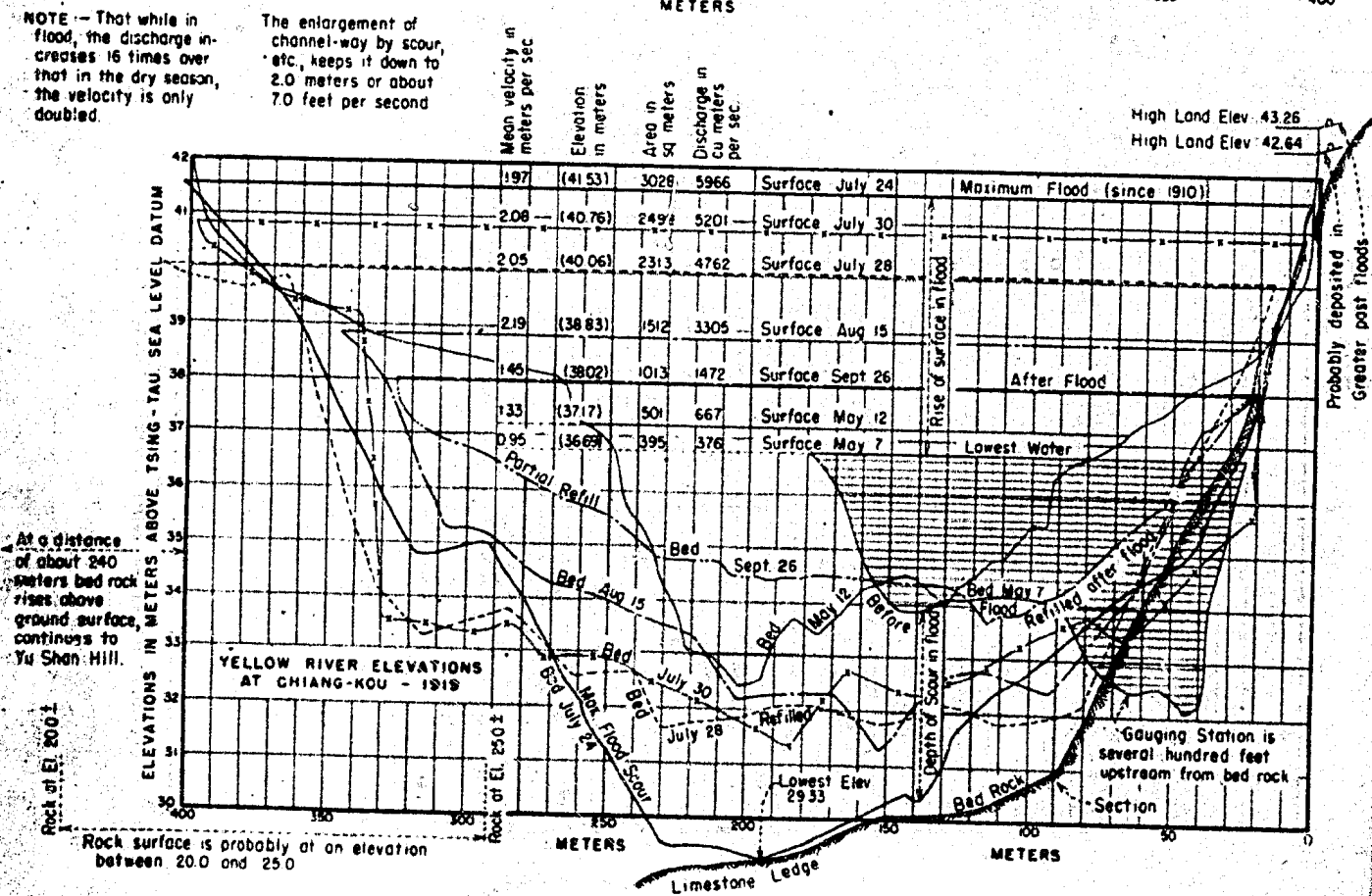


FIGURE 4  
 CHANGES OF COLORADO RIVER CROSS SECTION  
 YUMA, ARIZONA 1912, 1916 AND 1929



NOTE -- That while in flood, the discharge increases 16 times over that in the dry season, the velocity is only doubled.

The enlargement of channel-way by scour, etc., keeps it down to 2.0 meters or about 7.0 feet per second



considerable deepening of this stream at high flows. This "gaging station is located where the river runs between rock banks and is confined to a comparatively limited width." During the excavation for Hoover Dam a sawed and planed 2- by 6-inch plank was found in the riverbed material 50 feet below low-water surface and 40 feet below the bottom of the river channel. This showed that at some comparatively recent time the river in this canyon had scoured out the bed to the depth of this plank.

#### Analysis of Available Data

An examination of the foregoing data shows that, at most of the gaging stations mentioned, the bottom unquestionably goes down considerably at high flows. All of the cases where the bottom went down were either, (1) at bridges where the presence of piers would induce scour, (2) stations where the river was narrow, or (3) where it was probably narrow because measuring stations are usually where the river is narrow. The only place where a stream was measured from a cableway and where it was definitely known to be at a section which was not contracted, was on the Lower Colorado River at the site of the Imperial Dam. At this point no lowering of the bed was observed, but there is a slight chance that the conditions at this station might be influenced by the dam 6 miles downstream. We also have the evidence from the volume of material carried into the Elephant Butte Reservoir that no great average depth of material is scoured from the Rio Grande bed in floods and carried into the reservoir. Evidence pointing to a similar conclusion is the fact that the concentration of sediment carried in most streams in floods is insufficient to carry the amounts excavated if the lowerings indicated by measurements at most gaging stations are typical of the whole length and width of the river.

An explanation which is consistent with all the observed data except that taken at the site of the Imperial Dam is that the river behaves as described by F. N. Holmquist in the article previously quoted. He believed that rivers of the type under discussion in floods excavate a deep channel over only a portion of their width, depositing the material excavated in the shallower portions of the channel a short distance downstream. This deep channel he believed tends to approach the outside of the bends and thus, in flowing downstream, it may cross from one side of the river channel to the other. It constantly shifts in position usually by side erosion, but occasionally by avulsion (a complete and sudden abandonment of a portion of its former course and adoption of a new channel).

#### Observations during the Rio Grande Flood of May 1948

After the foregoing studies were completed, an opportunity was had to observe both from the ground and the air the conditions during the flood at the end of May 1948, at which time the flow at Albuquerque reached about 13,000 second-feet. A flight over the river from Cochiti to the Elephant Butte Reservoir was particularly illuminating.

A special effort was made during these observations to determine the existence of a narrow deep channel, such as that described by Holmquist, but no evidence was found of such a phenomenon. The fact that the location of bridges and gaging stations is nearly always at narrow sections of the river, however, was definitely established. That these narrow sections scour out during floods seemed very reasonable, but it appeared to be deposited at the next wide section downstream, and not carried on down the river. This explanation would fit in with all of the observed data, which tends to confirm the accuracy of this tentative conclusion.

#### Necessity for Quantitative Data on Rio Grande Bed Scour

The attempts made to estimate the rate of degradation which will occur after the completion of the sediment storage reservoirs as described elsewhere in this report, have shown that in order to make quantitative estimates, it is necessary to know the depth and width of the material worked over by the stream, since it is by the removal of the fine particles from this portion of the stream bed which causes degradation. These attempts have not disclosed any method of determining the lowering with a satisfactory degree of exactness without this knowledge. It is, therefore, imperative that further studies be made to quantitatively determine the magnitude of this movement.

The studies necessary to get the required information should be along three lines of approach as follows:

- (1) A detailed analysis of the bottom scour at stream gaging stations on the Rio Grande and similar streams, particularly where measurements were made from cableways.
- (2) The installation at numerous points in the bed of the Rio Grande of vertical cores of colored sand, the position of which was tied in to fixed points on the bank. These should be located both in the narrow and wide sections. After high floods the position of these cores would be relocated and excavations made to determine the depth to which they had been washed away, and therefore the depth of the bed which had been worked over. These will show whether the riverbed scours down at the wide as well as at the narrow sections.
- (3) A detailed study of the bed material and depth of degradation which has occurred in the Colorado River below Lake Mead, to show the depth of material worked over in the degradation which has taken place in that stream.

### Value of These Studies in the Solution of Other Problems

The data which would be secured from the studies outlined above would be of great value in the solution of many other problems which arise in the work of the Bureau of Reclamation. For example, a knowledge of the nature and extent of the lowering which takes place in the Rio Grande in high flows would be of the greatest assistance in working out the best method of confining the river below the sediment storage dams, in order to induce a more rapid rate of degradation.

A method of determining, with reasonable certainty, the degradation which will occur below any dam provided on a movable bed river is one of the greatest needs in the Bureau's design department. To provide a safe design for a considerable lowering of the tailwater level at these dams often greatly increases their cost, and should not be done unless necessary. However, if lowering is not provided for and it occurs, expensive repairs or the failure of the structure, often results. The data from the studies outlined would be of great help in working out such a method of estimating degradation.

### Appendix III .

#### EFFECT OF TEMPERATURE ON SEDIMENT TRANSPORTATION

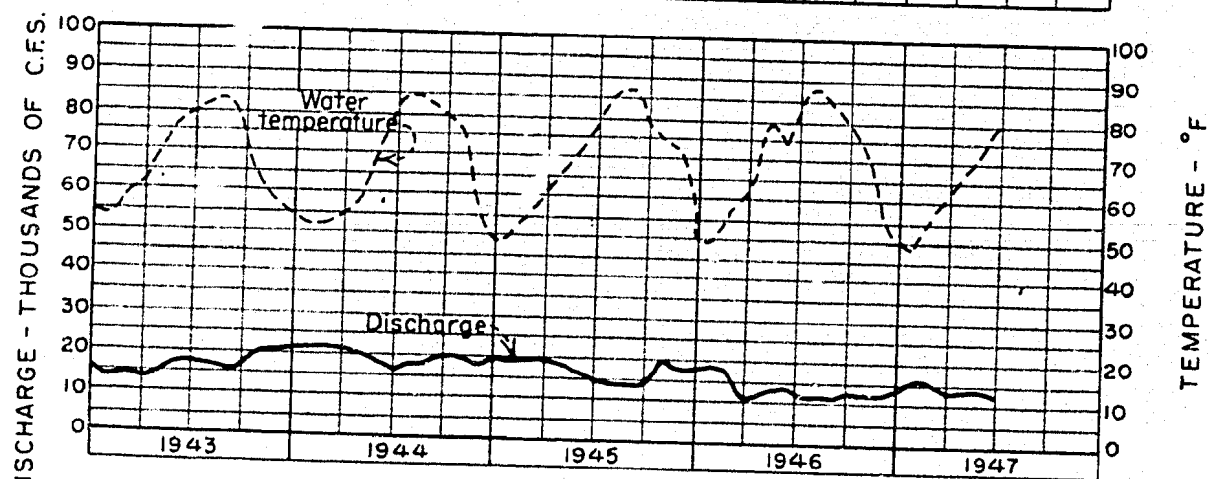
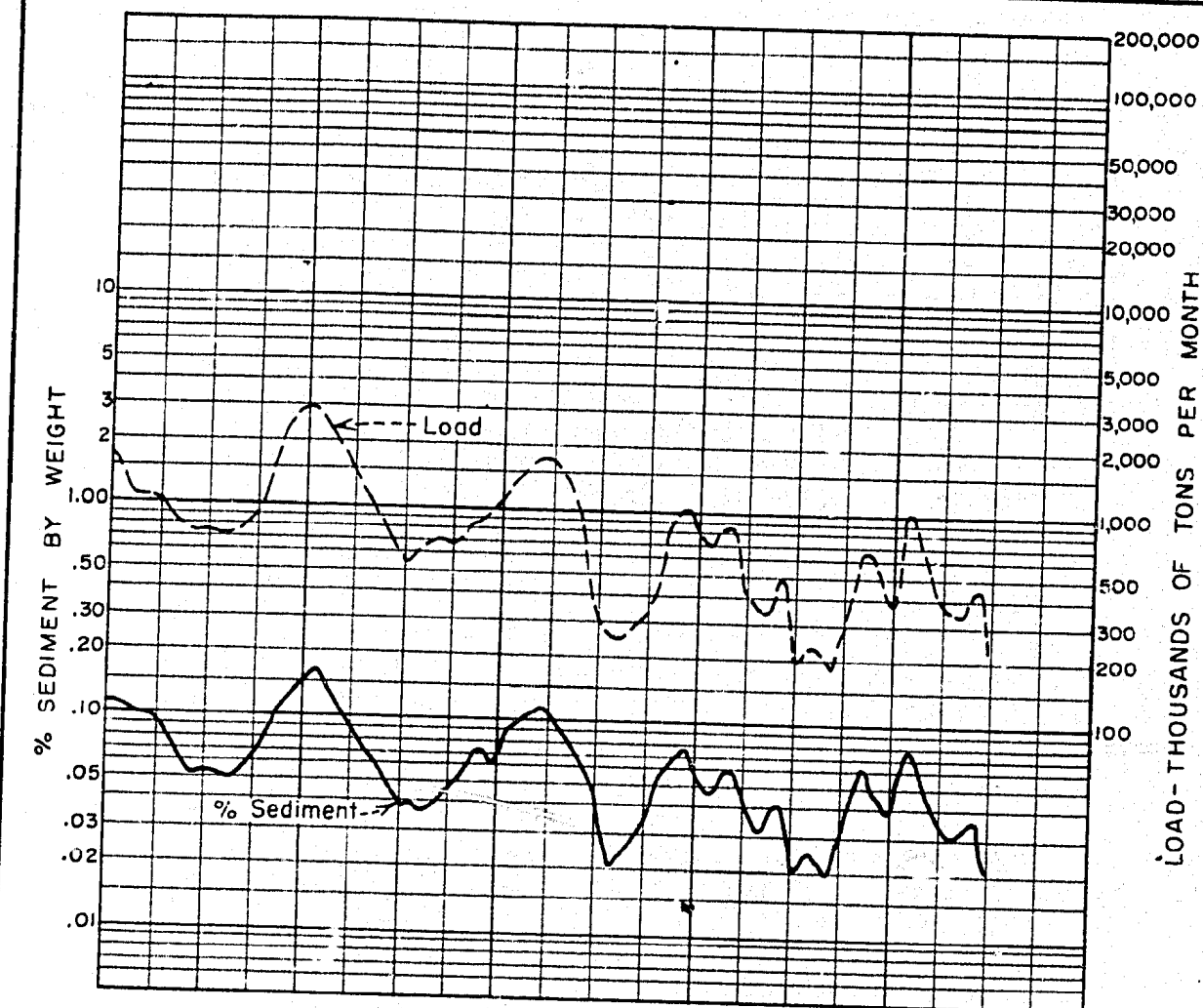
##### Sediment Fluctuations in the Lower Colorado River

The record of sediment discharge above the Imperial Dam reservoir on the Lower Colorado River shows a surprisingly much larger load of sediment in winter than in summer for approximately the same water discharge. This was first pointed out by R. E. Goss. Since the only obvious difference in the conditions at these two times of year is the difference of the temperature of the water, these results raise a serious question regarding the effect of temperature on the transportation of sediment in flowing streams.

The results of these sediment observations are shown on Figure 1, which gives the water discharge, water temperature, sediment concentration and sediment load at Taylors Ferry from 1943 to 1947, inclusive. It will be noted that for a given discharge, the sediment load may be as much as 2-1/2 times as great in winter as in summer. The conditions in this stretch of the Lower Colorado River are exceptionally favorable to indicating any effect temperature may have, as the number of variables which might effect the sediment load is much less than in most rivers. This station is located downstream from the Hoover and Parker Reservoirs, in which the sediment coming down the Colorado is deposited, and clear water is discharged from them. Because of the regulating effect of these two reservoirs, the flow of the river is unusually uniform. There is very little local inflow between the Parker Dam and Taylors Ferry and the sediment carried by the river is almost entirely picked up from the stream bed. Approximately 70 percent of this load is composed of fine and very fine sand. This stream is therefore much freer than most streams from great fluctuations of water discharge and of load of sediment brought into it by tributaries. Because of the relatively constant conditions, the effect of temperature would be much more apparent than in an ordinary stream.

It will be noticed that although the sediment concentration fluctuates, being generally larger in winter than in summer, there is distinct tendency of the sediment concentration and discharge to become smaller with the passage of time. This is due to the gradual coarsening of the riverbed from which the load is picked up. Size analysis of the bed and suspended sediments showed that they gradually become coarser, as shown on Figures 2 and 3, respectively. As the bed became coarser, the water was not able to pick up as large a load as before, but the particle size of the material that it did pick up was coarser. The principal changes in sediment load were therefore due to the changes of water discharge, the coarsening of the bed, the changes of temperature of the water and some other unknown cause which fluctuates with the seasons and may be wholly or partly the effect of temperature. Although temperature appears to be the most likely cause, so far as known no experiments have been made on the transporting power of water, in which only the temperature was varied. Until such experiments are made it cannot be positively stated that temperature is the cause, and therefore the cause must be regarded as unknown.





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BUREAU OF RECLAMATION  
**SEDIMENT STUDIES**  
COLORADO RIVER BASIN  
SUSPENDED LOAD AT TAYLOR'S FERRY  
DRAWN O.S.H. CHECKED DATE 6-29-48

FIGURE 1  
SUSPENDED SEDIMENT DATA COLORADO RIVER

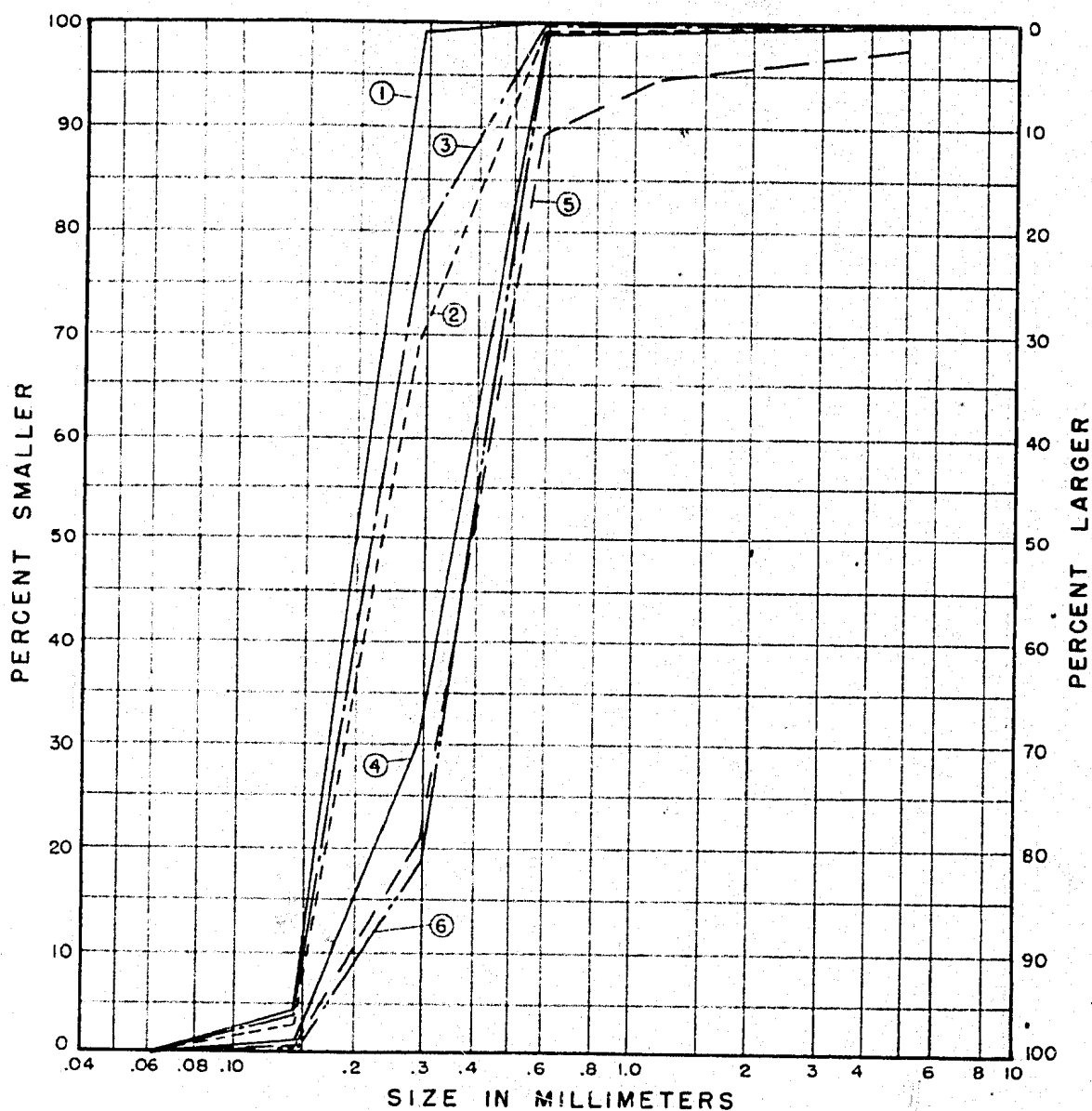
428

#### The Magnitude of the Fluctuations Due to the Unknown Cause as Shown by Using 1943 to 1947 Data

An attempt was therefore made to compute the magnitude of this effect, by eliminating the effect of the variation of water flow and stream bed coarsening. The first step was to eliminate the effect of water discharge. From many observations it has been found that the sediment load in natural streams varies roughly as the square of the discharge. This was expressed by an equation  $Q_s = K_a Q_w^2$ , where  $Q_s$  is the sediment load in tons per day,  $K_a$  is a constant and  $Q_w$  is the water discharge in second-feet. The values of  $K_a$  were found for all the sediment observations and plotted against calendar time as indicated on Figure 4. This shows approximately what the relative magnitude of the sediment load would have been had the discharge been uniform. An average line A-B was then drawn through the values of  $K_a$ , sloping gradually downward to indicate the approximate variation which the value of  $K_a$  would have had if this unknown cause had not been present. The slope of the line and the lower values of  $K_a$  represented by it, as time went on, are due to the coarsening of the bed. The ratio of the values of  $K_a$  as computed from the observed data to the value of  $K_0$  obtained from this average line should give a comparison of the magnitude of the fluctuations due to the effect of this unknown cause. Assuming that this fluctuation was entirely due to temperature, the magnitude of the ratio of the fluctuating  $K_a$  value to the gradually changing  $K_0$  value of the average line was plotted against the water temperature at the time of observation, with the result given on Figure 4. This shows that the ratio decreased with increasing temperature at a rate sufficient to make the average load at the time of lowest temperature about 2-1/2 times the average load at the time of highest temperature. It will thus be seen that whether or not this fluctuation is due to temperature, it is of so large a magnitude that its cause must be determined if accurate analyses are to be made of many sediment actions in the Lower Colorado River, and probably in the Middle Rio Grande as well. The sediment load shown on Figure 1 is the total load carried by the stream. An attempt was made to determine whether the effect of this cause was the same on particles of different sizes. To do this the total load was broken into four parts, each part composed of particles of a small size range, the four parts covering the entire range of sizes carried, which was from 0.044 mm to 0.589 mm. The load in each size range was analyzed in the same way as previously described for the total load. For sizes from 0.044 mm to 0.295 mm the temperature effect seemed to be very close to that shown on Figure 4. For the size 0.295 mm to 0.589 mm the change with temperature was negligible.

#### The Magnitude of the Fluctuations Shown by 1935 to 1942 Data

The results shown by the 1943 to 1947 data were confirmed by the data collected at Red Cloud Cable, Taylors Ferry and Imperial Damsite for the years 1935 to 1942, inclusive. During these years the sediment load and water discharge were determined by measurement, but the water temperature was not recorded. In working up this data a curve of the fluctuation of temperature throughout the year was drawn up by averaging the temperature as determined for the years



No. OF OBSERVATION	DATE OF OBSERVATION
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2	2-15-38
3	12-12-39
4	12-15-41
5	1-15-43
6	4-5-44

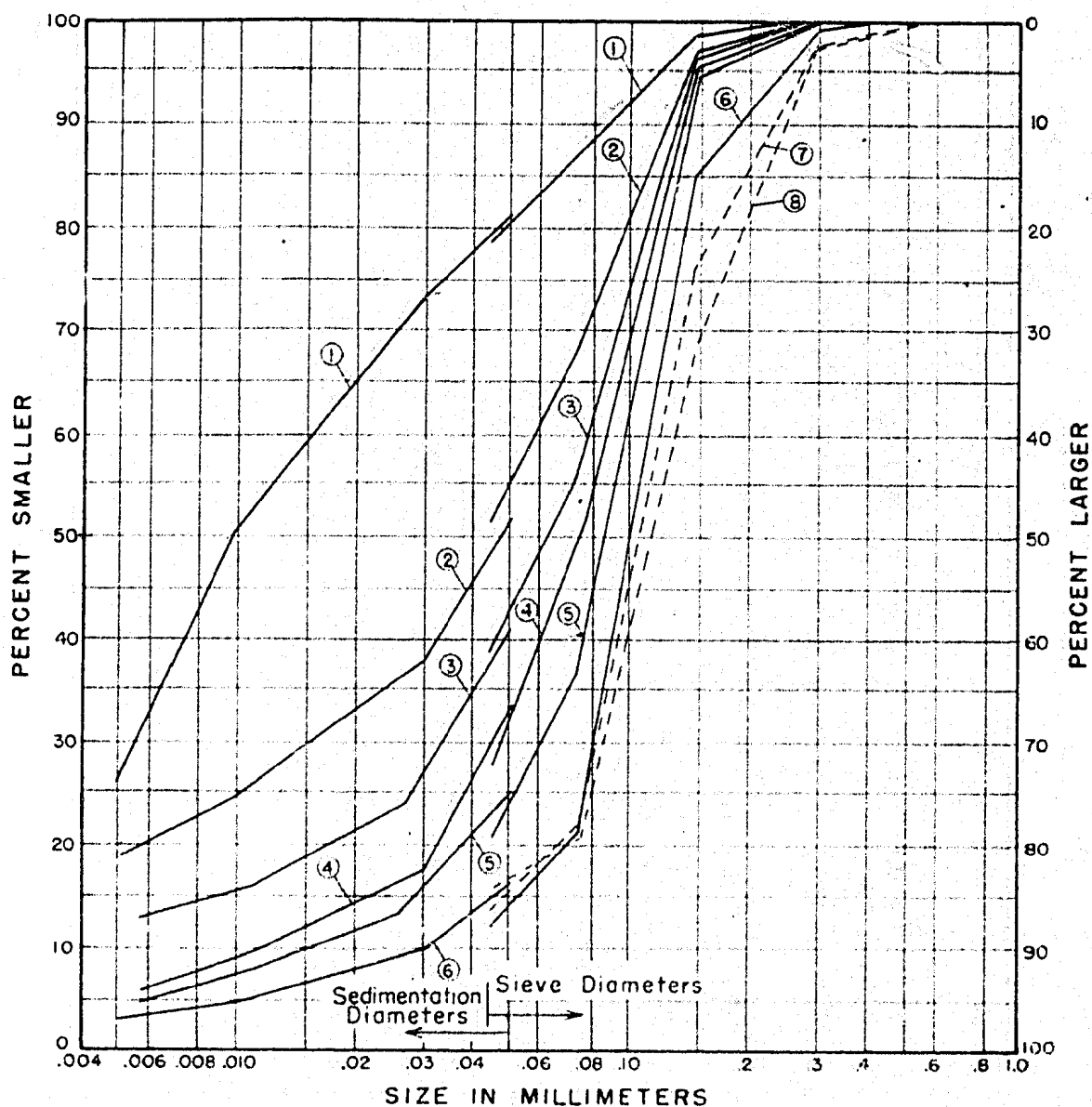
UNITED STATES  
DEPARTMENT OF THE INTERIOR  
BUREAU OF RECLAMATION  
**SEDIMENT STUDIES**  
COLORADO RIVER BASIN  
**SIZE ANALYSIS CHART**  
BED MATERIAL  
TAYLOR'S FERRY

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DATE 6-29-48

428

FIGURE 2  
SHOWING COARSENING OF BED MATERIAL IN COLORADO RIVER BED  
BELOW HOOVER AND PARKER DAMS



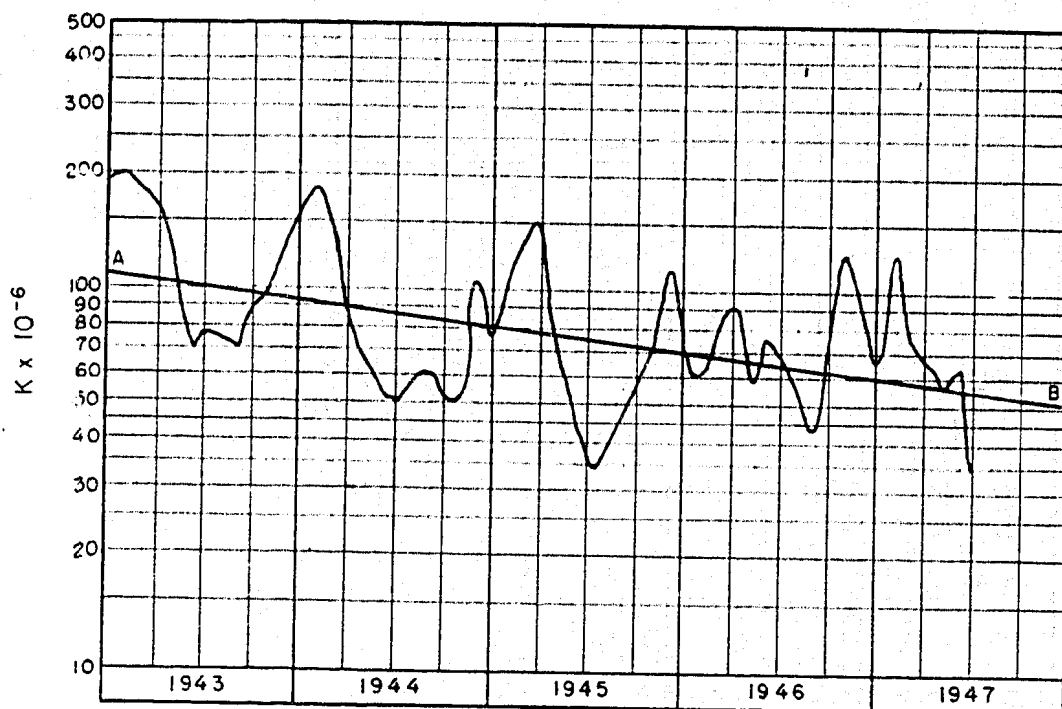
- ① May 1933 to Jan. 1934. Average of 69 samples from Imperial Dam site before closure of Hoover Dam.
- ② May 1935 to Jan. 1936. Average of 28 samples from Imperial Dam site after closure of Hoover Dam.
- ③ Year 1936. Average of 23 samples from Red Cloud Cable.
- ④ Years 1937 and 1938. Average of 52 samples from Red Cloud Cable.
- ⑤ Year 1939. Average of 35 samples from Red Cloud Cable and Taylor's Ferry.
- ⑥ Years 1940 and 1941. Average of 56 samples from Taylor's Ferry.
- ⑦ Years 1942 and 1943. Average of 30 samples from Taylor's Ferry.
- ⑧ Year 1944. Average of 10 samples from Taylor's Ferry.

NOTE  
Sedimentation diameters not determined for samples since 1941.

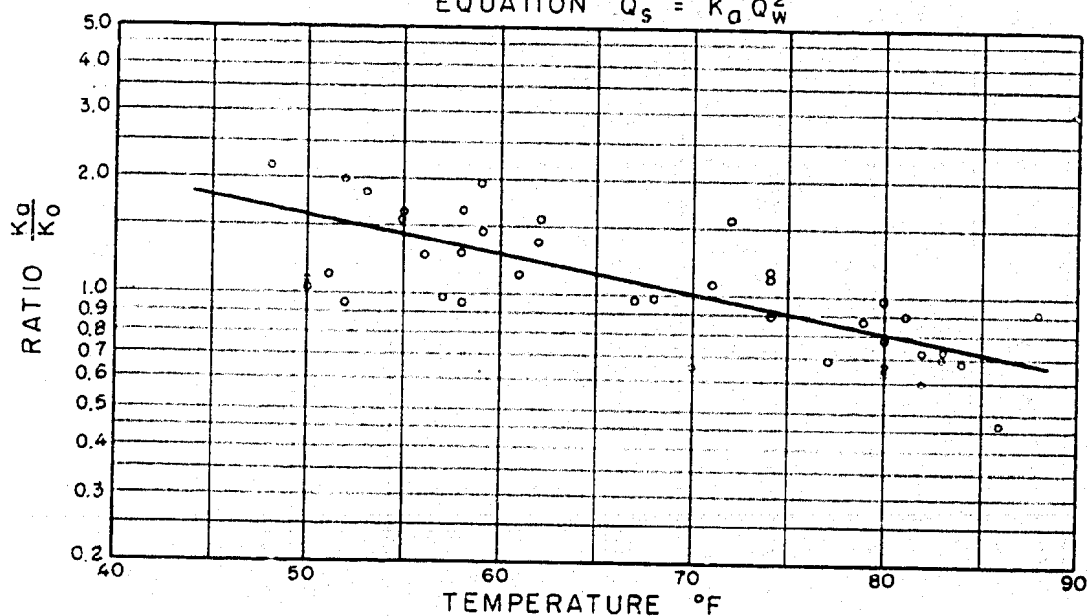
UNITED STATES  
DEPARTMENT OF THE INTERIOR  
BUREAU OF RECLAMATION  
**SEDIMENT STUDIES**  
COLORADO RIVER BASIN  
SIZE ANALYSIS CHART - SUSPENDED  
LOAD AT IMPERIAL DAMSITE,  
RED CLOUD CABLE, TAYLOR'S FERRY  
DRAWN O.S.H. CHECKED DATE 6-20-48

428

FIGURE 3  
SHOWING COARSENING OF SUSPENDED LOAD IN COLORADO RIVER  
BELOW HOOVER AND PARKER DAMS



SHOWING FLUCTUATING VALUE OF  $K_a$  WITH TIME IN  
EQUATION  $Q_s = K_a Q_w^2$



SHOWING VARIATION OF RATIO  $\frac{K_a}{K_0}$  WITH TEMPERATURE FOR  
COLORADO RIVER SUSPENDED LOAD DATA 1943-1947

NOTE:  $K_a = \frac{Q_s}{Q_w^2}$

$K_0$  = Value read from  
Average line A-B

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**SEDIMENT STUDIES**  
COLORADO RIVER BASIN  
SUSPENDED LOAD DATA AT  
TAYLOR'S FERRY

DRAWN O.S.H. CHECKED

DATE 6-29-48

428

FIGURE 4

1943 to 1947. Using the temperature indicated by this curve for the date on which each measurement was taken, Figure 5 was plotted, in the same manner as used in securing Figure 4. This shows practically the same fluctuation of sediment load with temperature as obtained for the years 1943 to 1947.

#### Experiments on the Effect of Temperature

The only experiments dealing with the effect of temperature on the movement of sediment were those of H<sub>o</sub> 9/, who experimented with the movement of coarse material in a glass-walled flume in Germany. He used water with temperatures ranging from 2° to 45° C, and found very much greater movement of material at higher temperatures than at lower temperatures. This effect is just the opposite of that found in the Lower Colorado River, where the movement was greater at lower temperatures. In his analysis of his results H<sub>o</sub> does not allow for the resistance of the sides of his flume. H<sub>o</sub>'s experiments have been analyzed by Einstein\*, who found that when this resistance was taken into account, allowing for the effect of temperature on its magnitude, the movement of sediment was practically the same at all temperatures for the same shear on the stream bed.

#### Temperature Effects in Sediment Transportation Formulae

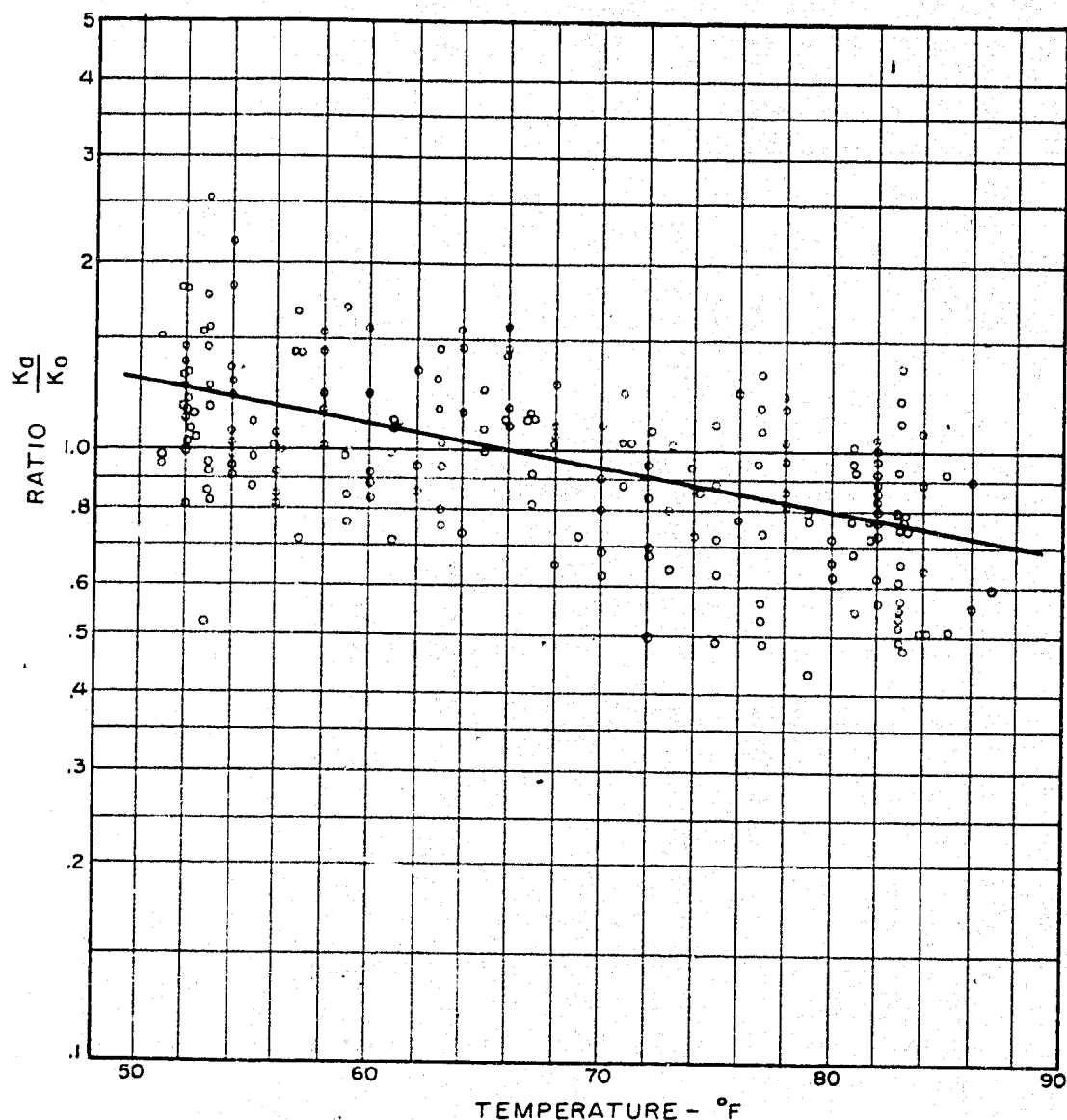
A study was also made of the effect of temperature on the transportation of sediment as indicated by the various formulae which have been proposed for computing the amount of sediment which would be transported by a stream of flowing water. The formulas of Schoklitsch 5/ and Straub 10/ do not consider any temperature effects. The bed (material) load formula of Einstein 11/ shows a small effect, the load decreasing with decreasing temperature. The magnitude of this effect decreases as the particle size of the material carried increases. The Lane-Kalinski 3/ relations for suspended load consider no effect of the temperature on the pickup of material from the bed, but show decreasing transport of the material in suspension, with increasing temperature. This difference is proportional to the change of settling rate of the sediment particles with temperature, due to the change of the viscosity of the water. The Kalinski 4/ bed-load formula shows a very slight effect of temperature, due to the change of density of the water with temperature,

Since the load of the Lower Colorado River was carried in suspension, the results should be analyzed as a problem in suspended load movement. The fluid mechanics of this phenomenon is now fairly well understood as regards the transportation of the sediment particles after they have been raised from the bed into suspension by the effect of the turbulence of the water, but a satisfactory analysis of the raising of the particles from the bed has not yet been worked out. The effect of temperature on the transportation of

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9 Numbers refer to references at end of report

\* Unpublished



NOTE:  $K_d = \frac{Q_s}{Q_w^2}$   
 $K_0$  = Average value  
 from Line A-B,  
 Figure 4

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**SEDIMENT STUDIES**  
 COLORADO RIVER BASIN  
 SUSPENDED LOAD DATA  
 IMPERIAL DAMSITE RED CLOUD CABLE  
 AND TAYLOR'S FERRY  
 DRAWN O.S.H. CHECKED DATE 6-29-48

428

FIGURE 5  
 SHOWING VARIATION OF RATIO  $\frac{K_d}{K_0}$  WITH TEMPERATURE FOR SUS-  
 PENDED SEDIMENT LOAD DATA ON COLORADO RIVER 1935-1942

sediment already in suspension is due to its effect on particle settling rate, as mentioned above, but the magnitude of these effects are much less than those indicated by the Lower Colorado River observations. For example, in a stream of 15 feet depth and velocity 5.72 feet per second with a concentration 0.2 percent at 1 foot above the bottom, the amount carried at 30° C, would vary from about 80 percent to 90 percent of what it would carry at 10° C, for sizes of uniform sediment, ranging from 1/4 to 1/6 mm, respectively.

If these Colorado River effects are due to temperature, since the temperature effects on transportation of sediment already in suspension are of much lesser magnitude, it follows that most of the effect of temperature observed in the Colorado River results is due to the temperature effect in the picking up of the material from the stream bed.

### Conclusion

From the foregoing discussion it seems very probable that temperature has a material effect on the transportation of sediment by a flowing stream, at least under the conditions which existed in the Lower Colorado River, since no other explanation of the fluctuation of the sediment load with the seasons there is readily apparent. However, until experiments are performed showing this effect under controlled conditions where the effect of changing only the temperature was observed, it would not be scientifically sound to conclude positively that temperature was the cause. In any event, until this matter is settled, a large measure of uncertainty must remain in any computations of sediment movement in the Middle Rio Grande Valley.



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SAMPLE COMPUTATIONS SHOWING METHOD OF COMPUTING  
DEGRADATION OR AGGRADATION ON THE MIDDLE RIO GRANDE RIVER

The following tables and figures show the method of computation as described in Appendix I.

Figure 1 shows the method of adjusting the normal flow duration curve to a curve of 5,000 cfs maximum flow. This adjustment was made by keeping the areas under the two curves equal. Table A shows the division of the flow into suitable increments and the percentage of time each increment can be expected to occur.

Table B shows the method of computing theoretical suspended load according to the Lane and Kalinske relations. Figure 2 is a graph of the relationship between  $t_c$  and  $N_oP/N_b$  that is used in these computations. From these results Figure 3, Sediment Discharge Curve, is plotted. From curves in Figure 3 and the flow duration, the computations shown in Tables C and D are made to find the amount of each size and total load carried for the 600-foot width and 5,000 cfs maximum discharge and the 1,200-foot width and normal discharge.

These same steps for the Kalinske bed load formula are shown in Tables E, F, and G, and Figures 4 and 5. The Schoklitsch formula computations are covered in Tables H, I, and J, and Figure 6.

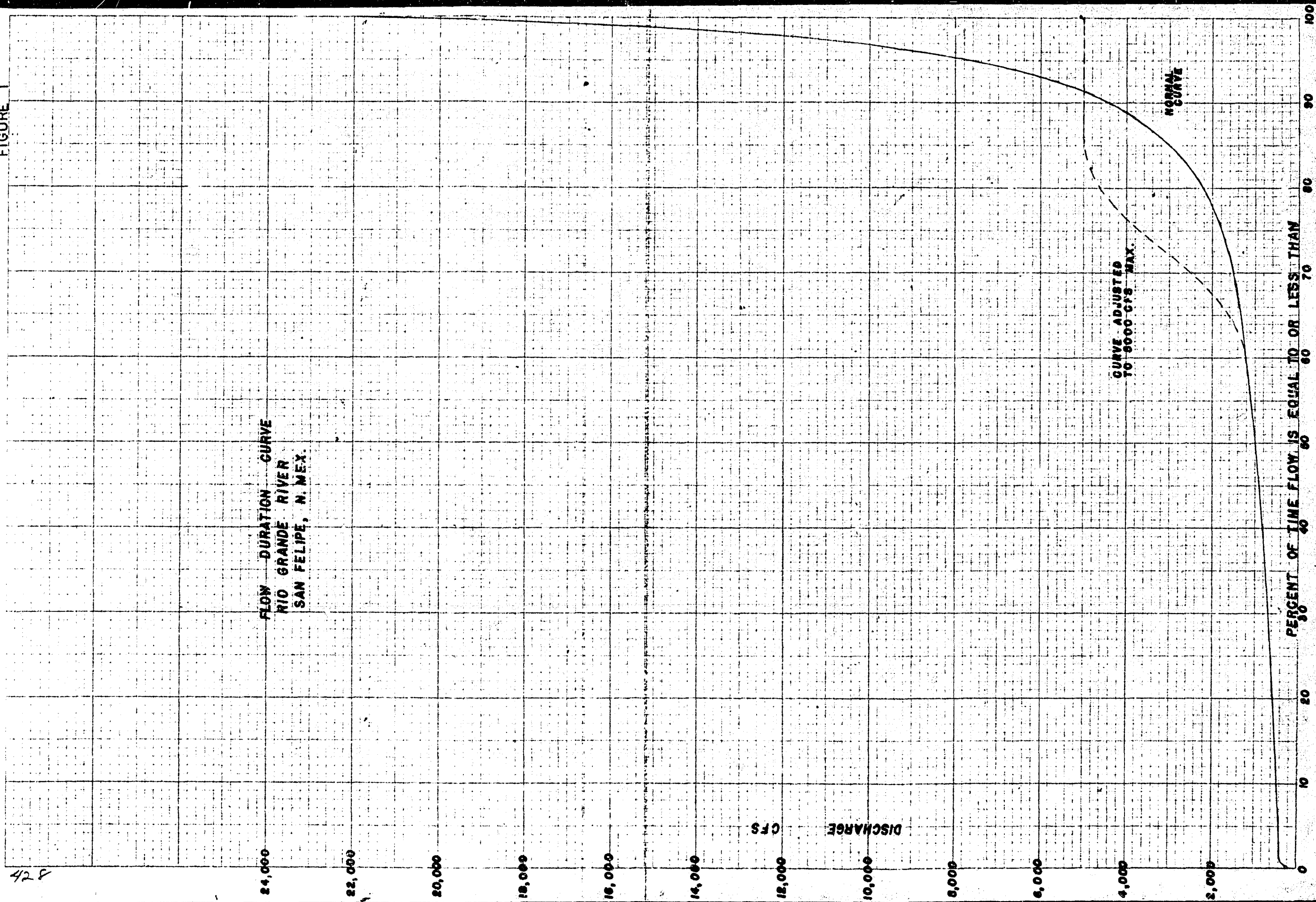
The load adjustments described in Step 3, Page 21, Appendix I are covered in Table K and Figure 7. The balance of the degradation computations are shown in Table L for three periods.

Table A

RIO GRANDE DEGRADATION STUDIES  
FLOW DURATION CALCULATIONS

NORMAL FLOW				REDUCED FLOW			
Q	%	Q av.	Flow duration % of time	Q	%	Q av.	Flow duration % of time
240	0.0			240	0.0		
		240	0.1			240	0.1
240	0.1			240	0.1		
		245	0.1			245	0.1
250	0.2			250	0.2		
		325	2.8			325	2.8
400	5.0			400	5.0		
		452.2	7.0			452.2	7.0
505	10.0			505	10.0		
		558	10.0			558	10.0
610	20.0			610	20.0		
		665	10.0			665	10.0
720	30.0			720	30.0		
		780	10.0			780	10.0
840	40.0			840	40.0		
		920	10.0			920	10.0
1000	50.0			1000	50.0		
		1100	10.0			1100	10.0
1200	60.0			1200	60.0		
		1365	10.0			1400	5.0
1530	70.0			1600	65.0		
		1890	10.0			1910	5.0
2250	80.0			2220	70.0		
		3275	10.0			3005	5.0
4300	90.0			3790	75.0		
		5850	5.0			3995	2.0
7400	95.0			4200	77.0		
		8700	2.0			4415	3.0
10000	97.0			4630	80.0		
		12550	2.0			4765	3.0
15100	99.0			4900	83.0		
		16450	0.5			4950	3.0
17800	99.5			5000	86.0		
		19500	0.4			5000	14.0
21200	99.9			5000	100.0		
		21600	0.1				
22000	100.0						

FIGURE 1



FLOW DURATION CURVE  
RIO GRANDE RIVER  
SAN FELIPE, N. MEX.

CURVE ADJUSTED  
TO 5000 CFS MAX.

NORMAL  
CURVE

DISCHARGE  
CFS

PERCENT OF TIME FLOW IS EQUAL TO OR LESS THAN

MIDDLE RIO GRANDE DEGRADATION STUDIES  
SUSPENDED LOAD  
LANE AND KALINSKE FORMULA

Basic data      Slope = 0.00096  
Mannings "n" = 0.025  
Temperature = 50° F

D	D 1/6	D 1/2	q <sub>w</sub>	$\frac{n}{D^{1/6}}$	$\sqrt{gDS}$	t <sub>c</sub>	$\frac{N_oP}{N_b}$	0.375 mm	q <sub>s</sub>	t <sub>c</sub>	$\frac{N_oP}{N_b}$	0.1875 mm	q <sub>s</sub>	t <sub>c</sub>	$\frac{N_oP}{N_b}$	0.09375 mm
0.50	0.891	0.707	0.580	0.0281	0.1245	1.26				0.50	0.248	0.032	0.154	10.8	1.415	
1.00	1.000	1.000	1.84	0.0250	0.1758	0.89	0.013	0.0054	0.35	1.04	0.431	0.109	23.5	9.73		
2.00	1.122	1.414	5.84	0.0222	0.2486	0.63	0.102	0.1340	0.25	3.10	4.073	0.077	45	59.1		
5.00	1.308	2.236	26.96	0.0191	0.3248	0.48	0.370	2.244	0.19	7.00	42.46	0.059	73	443		

U = depth in feet

$$Q_w = \text{water discharge in cfs per ft width} = (1.436/n) S^{1/2} P^{5/3}$$

$t_c = c/\sqrt{DS}$  where  $c$  = settling velocity in feet per second from graph in (Report No. 7--A Study of New Methods for Size Analysis of Suspended Sediment Samples)

Read from graph. Figure 2

$$= \text{sediment discharge pounds per hour per ft width for 1 percent of material of given size in the bed}$$

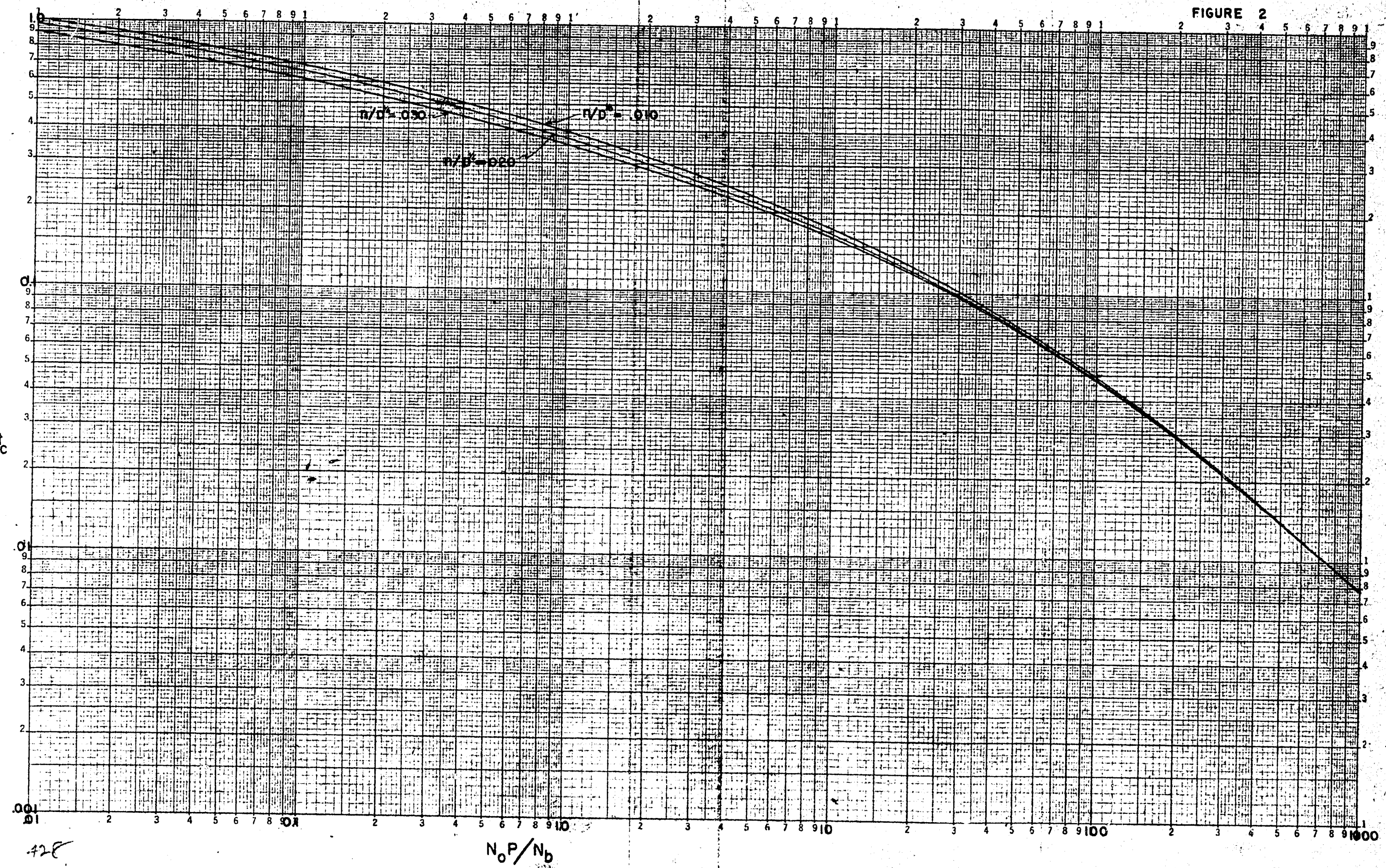
concentration of suspended material of a given size at the bottom

$\text{Wb} =$  percent of material of a given size found in the bed

= ratio of mean concentration in vertical to concentration of suspended material of a given size at the bottom



FIGURE 2



GEORGE A. LESSER CO., N. Y. NO. 345-1331  
LOGARITHMIC SCALE CYCLES  
MADE IN U.S.A.

428

$N_o P / N_b$

Table C

RIO GRANDE DEGRADATION STUDIES  
SUSPENDED LOAD  
LANE AND KALINSKE FORMULA

Basic data      Width            1,200 feet  
                  Slope            0.00096  
                  "n"            0.025  
                  Temperature    50° F  
                  Size gradation from average of two borings No. 37 and No. 51  
                  Normal flow duration at San Felipe

Flow:	:	:	:	:	:	:	:	:	:
Q <sub>w</sub> : duration:	Q <sub>w</sub> :	.09375 mm :	.1875 mm :	.375 mm :					
Cfs :	Cfs/ft :	q <sub>s</sub> :	Q <sub>s</sub> :	q <sub>s</sub> :	Q <sub>s</sub> :	q <sub>s</sub> :	Q <sub>s</sub> :		
% :	ft :	q <sub>s</sub> :	Q <sub>s</sub> :	q <sub>s</sub> :	Q <sub>s</sub> :	q <sub>s</sub> :	Q <sub>s</sub> :		
time:	:	:	:	:	:	:	:		
240:	0.1:	0.200:	0.22:	0.005:	0.0022:	:	:	:	:
245:	0.1:	0.204:	0.23:	0.005:	0.0024:	:	:	:	:
325:	2.8:	0.271:	0.38:	0.224:	0.0050:	0.019:	:	:	:
452:	7.0:	0.377:	0.68:	1.022:	0.0122:	0.116:	:	:	:
558:	10.0:	0.465:	0.98:	2.105:	0.0187:	0.254:	:	:	:
665:	10.0:	0.554:	1.33:	2.856:	0.0285:	0.387:	:	:	:
780:	10.0:	0.650:	1.75:	3.758:	0.042 :	0.571:	:	:	:
920:	10.0:	0.766:	2.32:	4.983:	0.062 :	0.842:	:	:	:
1100:	10.0:	0.917:	3.15:	6.765:	0.093 :	1.264:	:	:	:
1365:	10.0:	1.14 :	4.5 :	9.665:	0.153 :	2.079:	:	:	:
1890:	10.0:	1.57 :	7.6 :	16.323:	0.305 :	4.144:	0.0033:	0.062:	:
3275:	10.0:	2.73 :	18.3 :	39.303:	0.97 :	13.180:	0.017 :	0.319:	:
5850:	5.0:	4.88 :	44.5 :	47.786:	2.95 :	20.041:	0.085 :	0.797:	:
8700:	2.0:	7.25 :	80 :	34.363:	5.8 :	15.761:	0.218 :	0.204:	:
12550:	2.0:	10.5 :	135 :	57.988:	10.8 :	29.349:	0.46 :	1.726:	:
16450:	0.5:	13.7 :	190 :	20.403:	16.0 :	10.870:	0.73 :	0.685:	:
19500:	0.4:	16.2 :	225 :	19.329:	20.5 :	11.142:	1.00 :	0.750:	:
21600:	0.1:	18.0 :	275 :	5.906:	24.0 :	3.261:	1.18 :	0.221:	:
:	:	:	:	:	:	:	:	:	:
TOTAL LOAD									
Total load T/yr/ft		272.789:		113.280:		4.764:			
Total load T/yr		327,347 :		135,936 :		5,717 :		469,000 T/yr	
		:		:		:		:	
Percent of total load		69.79 :		28.98 :		1.22 :			

Q<sub>w</sub> = average water discharge in cfs for percent of time shown under flow duration taken from flow duration curve

Q<sub>w</sub> = water discharge in cfs/ft width = Q<sub>w</sub>/width

q<sub>s</sub> = sediment discharge in lb/hr/ft width read from sediment discharge graph

Q<sub>s</sub> = sediment discharge in T/yr/ft width =

$(q_s)(24)(365.25)(\% \text{ of size in bed})(\text{flow duration})$

2,000

100

Table D

RIO GRANDE DEGRADATION STUDIES  
SUSPENDED LOAD  
LANE AND KALINSKE FORMULA

Basic data:      Width            600 feet  
                 Slope            0.00096  
                 "n"            0.025  
                 Temperature    50° F  
                 Size gradation from average of two borings  
                 No 37 and No 51  
                 Flow duration at San Felipe adjusted to  
                 5000 cfs max

Flow :	:	:	:	:	:	:	:	:	:
dura-:	:	.09375 mm	:	.1875 mm	:	.375 mm	:	:	:
tion :	Q <sub>w</sub> :	Q <sub>s</sub> :	Q <sub>s</sub> :	Q <sub>s</sub> :	Q <sub>s</sub> :	Q <sub>s</sub> :	Q <sub>s</sub> :	Q <sub>s</sub> :	:
:	:	:	:	:	:	:	:	:	:
240:	0.1 :	0.400:	0.760:	0.016:	0.0130:	0.002:	:	:	:
245:	0.1 :	0.408:	0.765:	0.016:	0.0132:	0.002:	:	:	:
325:	2.8 :	0.504:	1.12 :	0.674:	0.023 :	0.088:	:	:	:
452:	7.0 :	0.754:	2.25 :	3.383:	0.060 :	0.571:	:	:	:
558:	10.0 :	0.930:	3.22 :	6.916:	0.097 :	1.318:	:	:	:
665:	10.0 :	1.108:	4.35 :	9.342:	0.145 :	1.970:	:	:	:
780:	10.0 :	1.300:	6.30 :	13.531:	0.202 :	2.745:	0.0018:	0.034:	:
920:	10.0 :	1.533:	7.30 :	15.678:	0.29 :	3.940:	0.0031:	0.058:	:
1100:	10.0 :	1.833:	9.7 :	20.833:	0.425 :	15.775:	0.0053:	0.099:	:
1400:	5.0 :	2.333:	14.3 :	15.356:	0.60 :	4.076:	0.0105:	0.098:	:
1910:	5.0 :	3.133:	23 :	24.699:	1.29 :	8.764:	0.026 :	0.244:	:
3005:	5.0 :	5.008:	61 :	65.505:	4.23 :	28.737:	0.091 :	0.854:	:
3995:	2.0 :	6.658:	71 :	30.497:	5.00 :	13.587:	0.180 :	0.675:	:
4415:	3.0 :	7.358:	81 :	52.189:	5.9 :	24.050:	0.222 :	1.249:	:
4765:	3.0 :	7.942:	91 :	58.632:	6.8 :	27.718:	0.264 :	1.486:	:
4950:	3.0 :	8.250:	96 :	61.854:	7.2 :	29.349:	0.283 :	1.593:	:
5000:	14.0 :	8.333:	97 :	291.658:	7.3 :	138.862:	0.290 :	7.616:	:
:	:	:	:	:	:	:	:	:	:
									TOTAL LOAD
Total T/yr/ft width		670.799:		291.554:		14.006:			
Total T/yr		402,467	:	174,932	:	8,404	:	585,803 T/yr	
			:		:		:		
Percent of total load		68.70 :		29.86 :		1.44 :			

$Q_w$  = average water discharge cfs for percent of time shown under flow duration; taken from flow duration curve

$Q_w$  = water discharge cfs/ft width =  $Q_w$ /width

$Q_s$  = sediment discharge in lb/hr/ft width read from sediment discharge graph

$Q_s$  = sediment discharge in T/yr/ft width =

$$\frac{(Q_s) (24) (365.25) (\text{percent of size in bed}) (\text{flow duration})}{2,000 \quad 100}$$



FIGURE 3

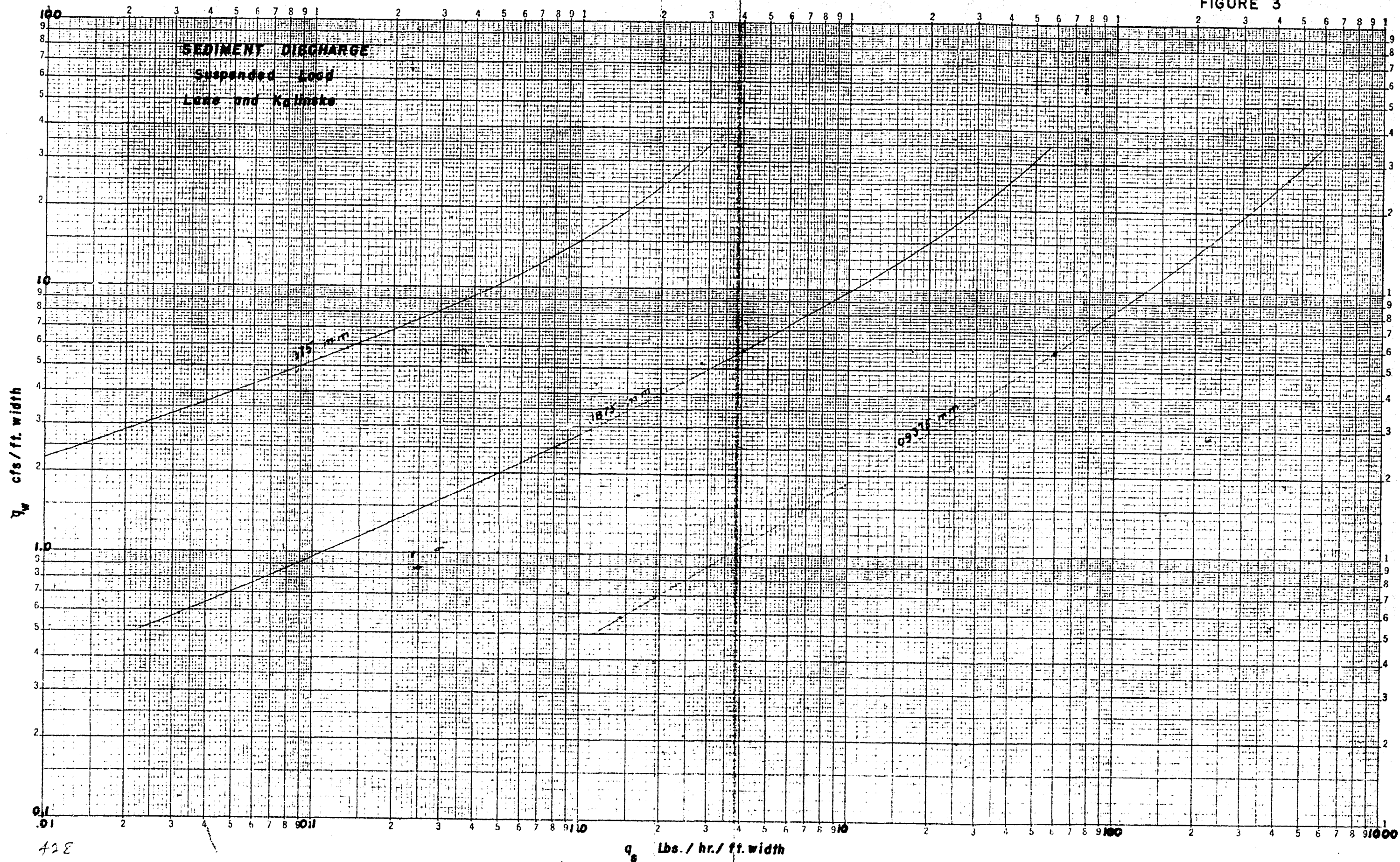


Table E

## MIDDLE RIO GRANDE DEGRADATION STUDIES

## BED LOAD

## KALINSKE FORMULA

Basic Data: Slope  $S = .00096$   
 Mannings "n" .025  
 Temperature  $50^{\circ} F$

D	$q_w$	$\tau_o$	$V^*$	Dia mm	Dia ft	$\tau_{cs}$	$\frac{\tau_c}{\tau_o}$	$\bar{u}_* / \bar{u}$	$q_b$
0.25	0.182	0.0150	0.0876	0.09375	0.0003076	0.003691	0.246	0.505	91.197
:	:	:	:	0.1875	0.0006152	0.007382	0.492	0.308	111.393
:	:	:	:	0.375	0.00123	0.01476	0.984	0.103	74.472
:	:	:	:	0.75	0.00246	0.02952	1.968	0.0058	8.362
:	:	:	:	1.50	0.00492	0.05904	3.936	:	:
0.50	0.580	0.300	0.1756	0.09375	0.0003076	0.003691	0.123	0.640	163.933
:	:	:	:	0.1875	0.0006152	0.007382	0.246	0.505	258.759
:	:	:	:	0.375	0.00123	0.01476	0.492	0.308	315.560
:	:	:	:	0.75	0.00246	0.02952	0.984	0.103	211.110
:	:	:	:	1.50	0.00492	0.05904	1.968	0.0058	23.825
1.00	1.84	0.0599	0.1756	0.09375	0.0003076	0.003691	0.062	0.750	271.697
:	:	:	:	0.1875	0.0006152	0.007382	0.123	0.640	463.715
:	:	:	:	0.375	0.00123	0.01476	0.246	0.505	731.626
:	:	:	:	0.75	0.00246	0.02952	0.492	0.308	892.404
:	:	:	:	1.50	0.00492	0.05904	0.984	0.103	596.882
:	:	:	:	3.00	0.00984	0.11808	1.968	0.0058	67.214
2.00	5.84	0.1198	0.248	0.09375	0.0003076	0.003691	0.031	0.830	424.586
:	:	:	:	0.1875	0.0006152	0.007382	0.062	0.750	767.442
:	:	:	:	0.375	0.00123	0.01476	0.123	0.640	1309.416
:	:	:	:	0.75	0.00246	0.02952	0.246	0.505	2066.287
:	:	:	:	1.50	0.00492	0.05904	0.493	0.308	2520.536
:	:	:	:	3.00	0.00984	0.11808	0.986	0.103	1685.722
:	:	:	:	6.00	0.01968	0.23616	1.971	0.0057	186.654
4.00	18.58	0.2396	0.351	0.09375	0.0003076	0.003691	0.015	0.900	651.789
:	:	:	:	0.1875	0.0006152	0.007382	0.031	0.830	1201.968
:	:	:	:	0.375	0.00123	0.01476	0.062	0.750	2171.684
:	:	:	:	0.75	0.00246	0.02952	0.123	0.640	3706.252
:	:	:	:	1.50	0.00492	0.05904	0.246	0.505	5849.062
:	:	:	:	3.00	0.00984	0.11808	0.493	0.308	7134.654
:	:	:	:	6.00	0.01968	0.23616	0.986	0.103	4771.898
:	:	:	:	12.00	0.03936	0.47232	1.971	0.0057	528.090

D = Depth in feet (NOTE: In original Kalinske paper symbol used for depth is "d")

$q_w$  = Water discharge in cfs/ft width =  $(1.486/n)s^{1/2}D^{5/3}$

$\tau_o$  =  $wDS$ ; where  $w$  is weight of water =  $62.4 \text{ #/ft}^3$

$v^* = \sqrt{\tau_o/\rho}$ ; where  $\rho$  is fluid mass density  $\frac{1.94 \text{ lbs sec}^2}{\text{ft}^4}$

$\tau_c$  =  $12 \times$  Diameter in feet

$\bar{U}_g/\bar{U}$  Read from Graph

$q_s$  = Sediment discharge in lb s/sec /ft for 100 percent of given size in bed

$q_s = (2.57)(\bar{U}_g/\bar{U})(v^*)(D \text{ in ft})(\gamma_g)$ ; where  $\gamma_g$  is specific weight of material  $(2.65)(62.4) = 165.4 \text{ #/ft}^3$

(NOTE: In original Kalinske paper symbol D used for diameter of particle in feet)

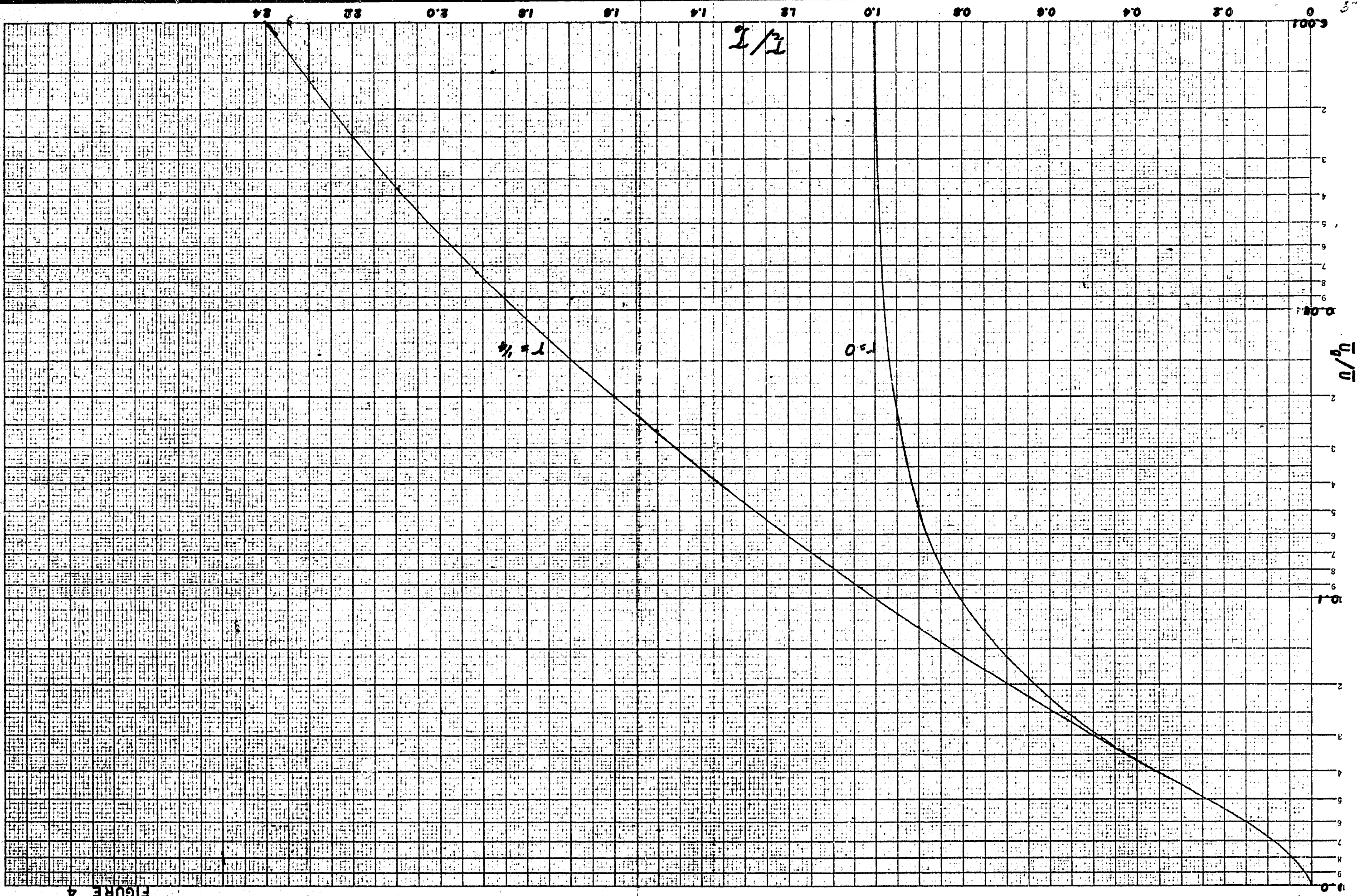




Table G

RIO GRANDE DEGRADATION STUDIES—BED LOAD  
KALISKE FORMULA

Basic data      Width      600 feet  
Slope      0.00096  
"n"      0.025  
Temperature      50° F

Size gradation from average of two borings No 37 and No 51  
Flow duration at San Felipe adjusted to 5000 cfs max

Flow:	0.09375 mm	0.1375 mm	0.375 mm	0.75 mm	1.5 mm	3.0 mm	6.0 mm
Q <sub>w</sub>	Q <sub>s</sub>	Q <sub>s</sub>	Q <sub>s</sub>	Q <sub>s</sub>	Q <sub>s</sub>	Q <sub>s</sub>	Q <sub>s</sub>
240:	0.1:0.400:138:	0.020:202:	0.095:	225:	0.073:	97:	0.005:
245:	0.1:0.408:139:	0.021:203:	0.095:	230:	0.075:	98:	0.005:
325:	2.8:0.504:152:	0.630:235:	3.196:	280:	2.540:	162:	0.227:
452:	7.0:0.754:185:	1.917:300:	9.849:	395:	8.959:	330:	1.155:
558:	10.0:0.930:202:	2.990:335:	15.712:	460:	14.904:	445:	2.225:
665:	10.0:1.108:220:	3.256:365:	17.119:	525:	17.010:	550:	2.750:
780:	10.0:1.300:236:	3.493:395:	18.526:	585:	18.954:	650:	3.250:
920:	10.0:1.533:252:	3.730:425:	19.933:	650:	21.060:	760:	3.800:
1100:	10.0:1.833:272:	4.026:465:	21.309:	730:	23.652:	890:	4.450:
1400:	5.0:2.333:300:	2.220:520:	12.194:	830:	13.446:	1080:	2.700:
1910:	5.0:3.183:335:	2.479:600:	14.070:	990:	16.038:	1360:	3.400:
3005:	5.0:5.008:400:	2.960:725:	17.001:	1230:	19.926:	1830:	4.575:
3995:	2.0:6.653:450:	1.332:820:	7.692:	1400:	9.072:	2200:	2.200:
4415:	3.0:7.358:460:	2.042:850:	11.960:	1450:	14.094:	2320:	3.450:
4765:	3.0:7.942:475:	2.109:880:	12.382:	1500:	14.580:	2420:	3.630:
4950:	3.0:8.250:482:	2.140:890:	12.522:	1520:	14.774:	2480:	3.720:
5000:	14.0:8.333:485:	10.049:895:	58.766:	1530:	67.401:	2500:	17.500:
Total load							
T/yr/ft width	45.414:	252.921:	278.558:	59.072:	7.173:	1.608:	0.138:
Total load T/yr	27,248	151,753	167,135	35,443	4,304	965	83
% of total load	7.04:	39.22:	43.20:	9.16:	1.11:	0.25:	0.02:

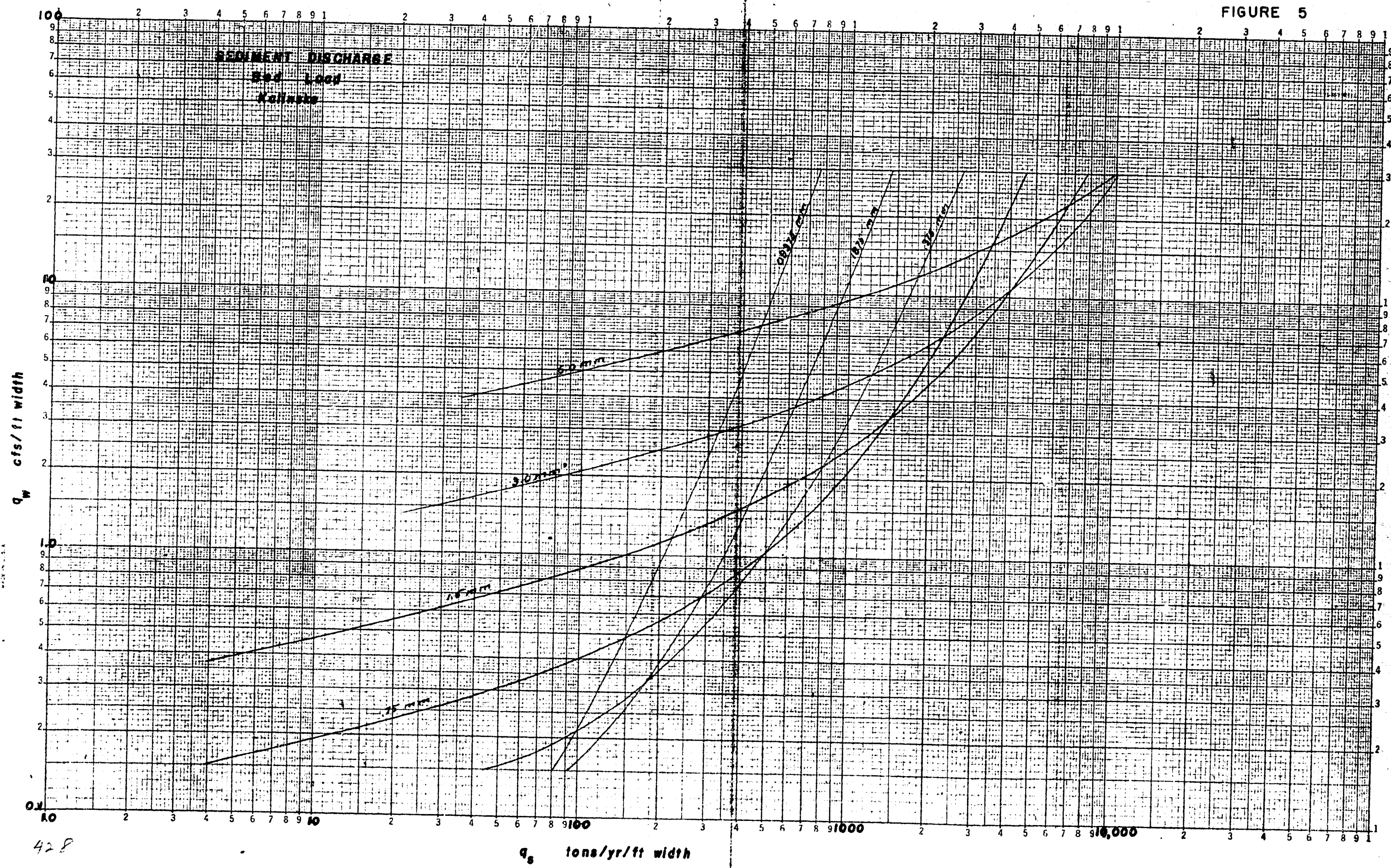
Q<sub>w</sub> = Average water discharge in cfs for percent of time shown under flow duration; taken from flow duration curve

q<sub>w</sub> = Water discharge in cfs/ft width = Q<sub>w</sub>/width

Q<sub>s</sub> = Sediment discharge in T/yr/ft width; read from sediment discharge curve

Q<sub>s</sub> = Sediment discharge in T/yr/ft width = (q<sub>s</sub>)(% in bed /100)(flow duration/100) Note: Percent in bed is percent of area covered by given size

FIGURE 5



KEUFFEL & ESSER CO. N. Y. NO. 135-1741  
Logarithmic, 5 x 2 1/2 in.  
22 x 22 in. 3.4

428

Table H

RIO GRANDE DEGRADATION STUDIES  
BED LOAD  
SCHOKLITSCH FORMULA

Basic data    Slope            .00096  
                 Mannings "n"        .025  
                 Temperature    50° F

	.09375 mm		.1875 mm		.375 mm		.75 mm		1.50 mm		3.0 mm		6.0 mm		12 mm	
	$q_w - q_o$	$q_s$	$q_w - q_o$	$q_s$	$q_w - q_o$	$q_s$	$q_w - q_o$	$q_s$	$q_w - q_o$	$q_s$	$q_w - q_o$	$q_s$	$q_w - q_o$	$q_s$	$q_w - q_s$	$q_s$
0.4:	0.1926:	29.5:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
0.5:	:	:	0.0352:	9.2:	:	:	:	:	:	:	:	:	:	:	:	:
0.8:	0.5926:	90.9:	0.3852:	41.7:	:	:	:	:	:	:	:	:	:	:	:	:
0.9:	:	:	:	:	0.0705:	5.4:	:	:	:	:	:	:	:	:	:	:
2.0:	1.7926:	274.6:	1.5852:	171.8:	1.1705:	89.8:	0.341:	18.4:	:	:	:	:	:	:	:	:
3.6:	:	:	:	:	:	:	:	:	0.282:	10.7:	:	:	:	:	:	:
4.0:	3.7926:	581.6:	3.5852:	388.5:	3.1705:	243.1:	2.341:	126.4:	0.682:	26.0:	:	:	:	:	:	:
8.0:	7.7926:	1195.1:	7.5852:	821.9:	7.1705:	549.8:	6.341:	342.4:	4.682:	178.7:	1.368:	37.0:	:	:	:	:
10.0:	9.7926:	1501.8:	9.5852:	1038.7:	9.1705:	703.2:	8.341:	450.4:	6.682:	255:	3.368:	91.1:	:	:	:	:
20.0:	19.7926:	3035.4:	19.5852:	2122.3:	19.1705:	1470:	18.341:	990.4:	16.682:	637:	13.368:	361:	6.737:	124:	:	:
30.0:	29.7926:	4569.0:	29.5852:	3205.9:	29.1705:	2237:	28.341:	1530.4:	26.682:	1018:	23.368:	632:	16.737:	321:	3.474:	47:
40.0:	39.7926:	6102.6:	39.5852:	4239.5:	39.1705:	3004:	38.341:	2070.4:	36.682:	1400:	33.368:	902:	26.737:	502:	3.474:	182.4:

$q_w$  = water discharge cfs/ft width

$q_o$  = critical discharge =  $0.00532D/(S^{4/3})$ ; where D is grain diameter in inches

$q_s$  = sediment discharge lb/hr/ft width where  $q_s = (86.7/\sqrt{D})(S^{1.5})(q_w - q_o)(3600)$ ; D is again diameter in inches; for 100 percent of material of given size in bed

Table I

RIO GRANDE DEGRADATION STUDIES  
BED LOAD  
SCHOKLITSCH FORMULA

Basic Data: Width 1200 ft  
Slope 0.00096  
"n" 0.025  
Temperature 50° F  
Size gradation from average of two borings #37 and # 51  
Normal flow duration at San Felipe

Flow : duration :	0.09375 mm :	0.1875 mm :	0.375 mm :	0.75 mm :	1.5 mm :	3.0 mm :	
$Q_w$ : : $q_w$ :	$q_s$ :	$Q_s$ :	$q_s$ :	$Q_s$ :	$q_s$ :	$Q_s$ :	$q_s$ :
240 : 0.1 : 0.200:	:	:	:	:	:	:	:
245 : 0.1 : 0.204:	:	:	:	:	:	:	:
325 : 2.8 : 0.271:	8 :	0.01:	:	:	:	:	:
452 : 7.0 : 0.377:	26 :	0.40:	:	:	:	:	:
558 : 10.0 : 0.465:	39 :	0.80:	:	:	:	:	:
665 : 10.0 : 0.554:	53 :	1.14:	15.7 :	2.13:	:	:	:
780 : 10.0 : 0.650:	67.5 :	1.45:	26 :	3.53:	:	:	:
920 : 10.0 : 0.766:	87 :	1.87:	38.2 :	5.19:	:	:	:
1100 : 10.0 : 0.917:	112 :	2.41:	53 :	7.20:	6.6 :	1.24:	:
1365 : 10.0 : 1.14 :	143 :	3.07:	78 :	10.60:	21.5 :	4.03:	:
1890 : 10.0 : 1.57 :	208 :	4.47:	126 :	17.12:	55 :	10.32:	:
3275 : 10.0 : 2.73 :	389 :	8.36:	255 :	34.65:	147 :	27.58:	58 :
5850 : 5.0 : 4.88 :	725 :	7.79:	490 :	33.30:	312 :	29.27:	173 :
8700 : 2.0 : 7.25 :	1100 :	4.73:	750 :	20.39:	495 :	18.57:	305 :
12550 : 2.0 : 10.50 :	1600 :	6.87:	1110 :	30.17:	750 :	28.14:	480 :
16450 : 0.5 : 13.70 :	2100 :	2.26:	1480 :	10.06:	990 :	9.29:	655 :
19500 : 0.4 : 16.20 :	2500 :	2.15:	1730 :	9.40:	1190 :	8.93:	790 :
21600 : 0.1 : 18.00 :	2750 :	0.59:	1930 :	2.62:	1330 :	2.50:	885 :
Total load T/yr/ft width							TOTAL LOAD
48.37 :	186.36 :	139.87 :	21.51 :	2.23 :	0.31 :	478,380 T/yr	
Total load T/yr							
58,044 :	223,632 :	167,844 :	25,812 :	2,676 :	372 :		
% of total load							
12.13 :	46.75 :	35.09 :	5.40 :	0.56 :	0.07 :		

$Q_w$  = Average water discharge in cfs for percent of time shown under flow duration; taken from flow duration curve

$q_w$  = Water discharge in cfs/ft width =  $Q_w$ /width

$q_s$  = Sediment discharge in lbs/hr/ft width; taken from sediment discharge curve

$Q_s$  = Sediment discharge in T/yr/ft width =  $(q_s \times 24 \times 365.25) (\% \text{ of size in bed}) (\text{flow duration})$

2000

100

100



Table J

## RIO GRANDE DEGRADATION STUDIES

BED LOAD

### SCHOKLITSCH FORMULA

Basic data      Width      600 feet

Slope	0.00096
-------	---------

"n"	0.025
-----	-------

Temperature 50° F

Size gradation from average of two borings No. 37 and No. 51

Flow duration at San Felipe adjusted to 5,000 cfs maximum

Flow duration at San Felipe adjusted to 2,000 cfs maximum															
Flow :	0.9375 mm		1.875 mm		3.75 mm		7.5 mm		1.5 mm		3.0 mm				
duration :															
Qw :	Qw	qs	Qs	qs	Qs	qs	Qs	qs	Qs	qs	Qs	qs	Qs	qs	
240 :	0.1	0.400	30	0.006											
245 :	0.1	0.408	30	0.007											
325 :	2.8	0.504	46	0.277	10.5	0.399									
452 :	7.0	0.754	84	1.236	37	3.519									
558 :	10.0	0.930	112	2.406	55	7.473	7.6	1.426							
665 :	10.0	1.108	114	2.449	74	10.054	22.0	4.127							
780 :	10.0	1.300	170	3.652	94	12.772	37.5	7.035							
920 :	10.0	1.533	205	4.403	120	16.304	56	10.505							
1100 :	10.0	1.833	250	5.370	153	20.788	78	14.632							
1400 :	5.0	2.333	325	3.498	205	13.927	113	10.540	33	0.947					
1910 :	5.0	3.183	450	4.833	300	20.381	180	16.883	79	2.268					
3005 :	5.0	5.008	735	7.894	495	33.628	322	30.202	182	5.225	63	0.442			
3995 :	2.0	6.658	990	4.253	670	18.207	450	16.883	270	3.101	123	0.345			
4415 :	3.0	7.358	1100	7.088	740	30.163	500	28.139	310	5.340	150	0.631			
4765 :	3.0	7.942	1190	7.668	810	33.016	550	30.952	345	5.943	175	0.737	36	0.076	
4950 :	3.0	8.250	1230	7.926	840	34.239	570	32.078	360	6.201	188	0.791	44	0.093	
5000 :	14.0	8.333	1250	18.795	850	161.685	575	151.010	363	29.181	190	3.732	46	0.451	
:	:	:	:	:	:	:	:	:	:	:	:	:	:	TOTAL LOAD	
Total load T/y <sup>1/2</sup> /ft width	81.781		416.555		354.412		58.206		6.678		0.620				
Total load T/yr	49,069		249,933		212,647		34,924		4,007		372		550,952 T/yr		
Percent of total load	8.91		45.35		38.60		6.34		0.73		0.07				

$Q_w$  = average water discharge in cfs for percent of time shown under flow duration; taken from flow duration curve

$$q_w = \text{water discharge in cfs/ft width} = Q_w / \text{width}$$

$q_s$  = sediment discharge in lb/hr/ft width; taken from sediment discharge curves

$$Q_s = \text{sediment discharge in T/yr/ft width} = \frac{(q_s)(24)(365.25)(\text{percent of size in bed})(\text{flow duration})}{2,000 \quad 100 \quad 100}$$

FIGURE 6

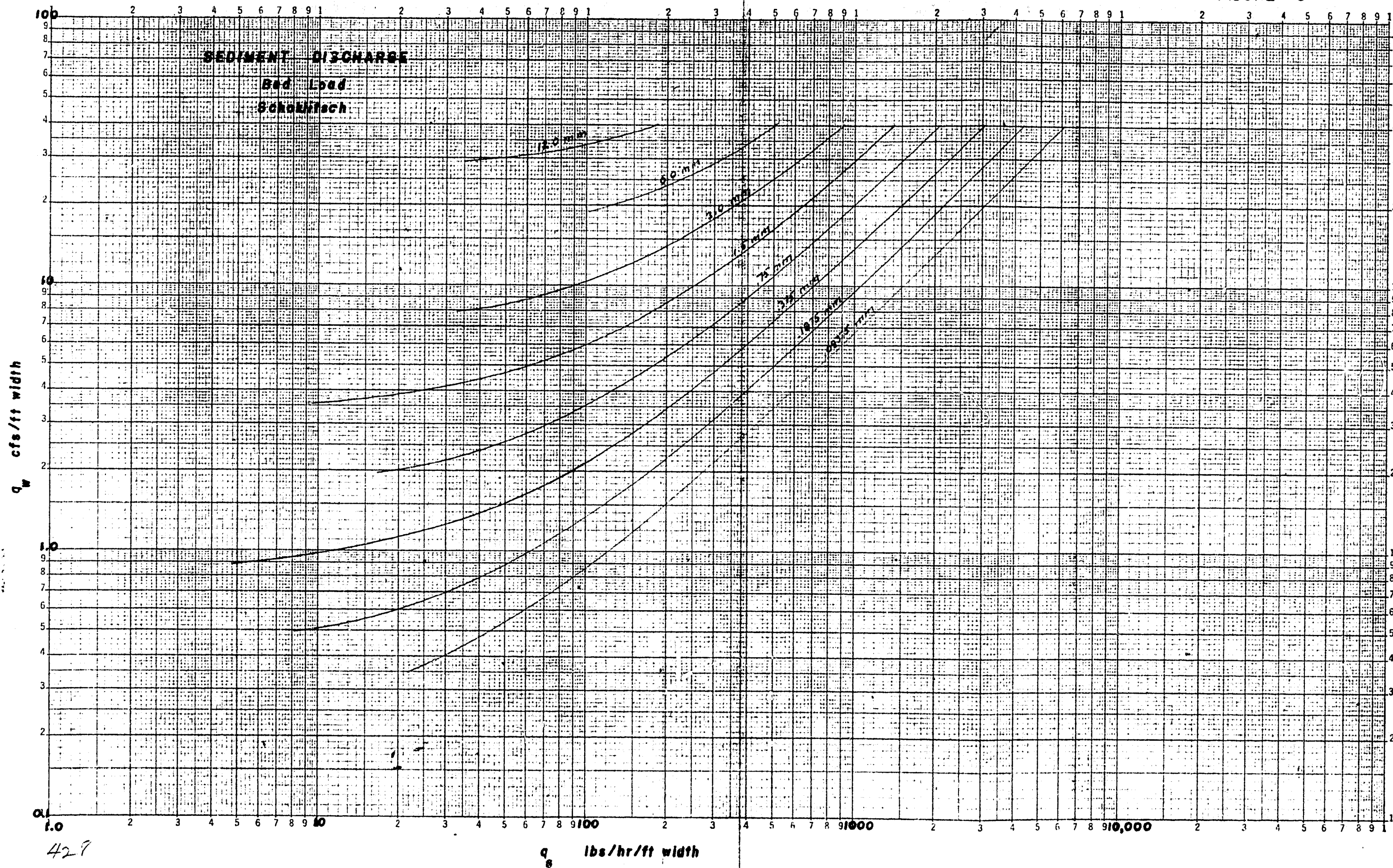


Table K

RIO GRANDE DEGRADATION STUDIES  
LOAD CALCULATIONS

	Suspended:	Bed load			Total
	load	Kalinske	Schoklitsch	Average	load
Normal width & flow :	469,000	506,507	478,380	492,444	961,444
Reduced width & flow:	585,803	386,931	550,952	468,941	1,054,744

Existing load in river from tabular estimate 2,350,000 tons/year

Corrected total load for new flow conditions  $\frac{(2,350,000)(1,054,744)}{961,444} = 2,578,047$

Bed load from theoretical average for new flow conditions

Suspended load for new flow conditions  $\frac{468,941}{2,109,106}$

To convert load from tons/year to equivalent depth over stretch

$\frac{(2,109,106)(2,000)}{(100)(81,607,680)} = 0.517 \text{ ft/yr}$  Suspended load =  $\frac{\text{Total susp ld tons} \times \text{lbs/ton}}{\text{lbs/cu ft} \times \text{area of river bed in stretch (sq ft)}}$

$\frac{(468,941)(2,000)}{(100)(81,607,680)} = 0.115 \text{ ft/yr}$  Bed load

To divide load into sizes according to theoretical percentages

	Suspended :	Bed load			Total
	load	Kalinske	Schoklitsch	Average	load
	%	Depth	%	%	Depth
Silt finer than .0625mm:	All of this size considered moved				
VFS .0625mm to .125mm:	68.70:0.355:	7.04	8.91	7.98	0.009:0.364
FS .125mm to .25mm:	29.86:0.154:	39.22	45.35	42.28	0.049:0.203
MS .25mm to .50mm:	1.44:0.008:	43.20	38.60	40.90	0.047:0.055
CS .50mm to 1.0mm:		9.16	6.34	7.75	0.009:0.009
VCS 1.0mm to 2.0mm:		1.11	0.73	0.92	0.001:0.001
VFG 2.0mm to 4.0mm:		0.25	0.07	0.16	— : —
FG 4.0mm to 8.0mm:		0.02		0.01	— : —
MG 8.0mm to 16.0mm:					
Coarser than 16.0mm:					
Total		0.517:			0.115:0.632

Ray diagram plotted using total depth shown in table above plotted against existing bed gradation.

FIGURE 7

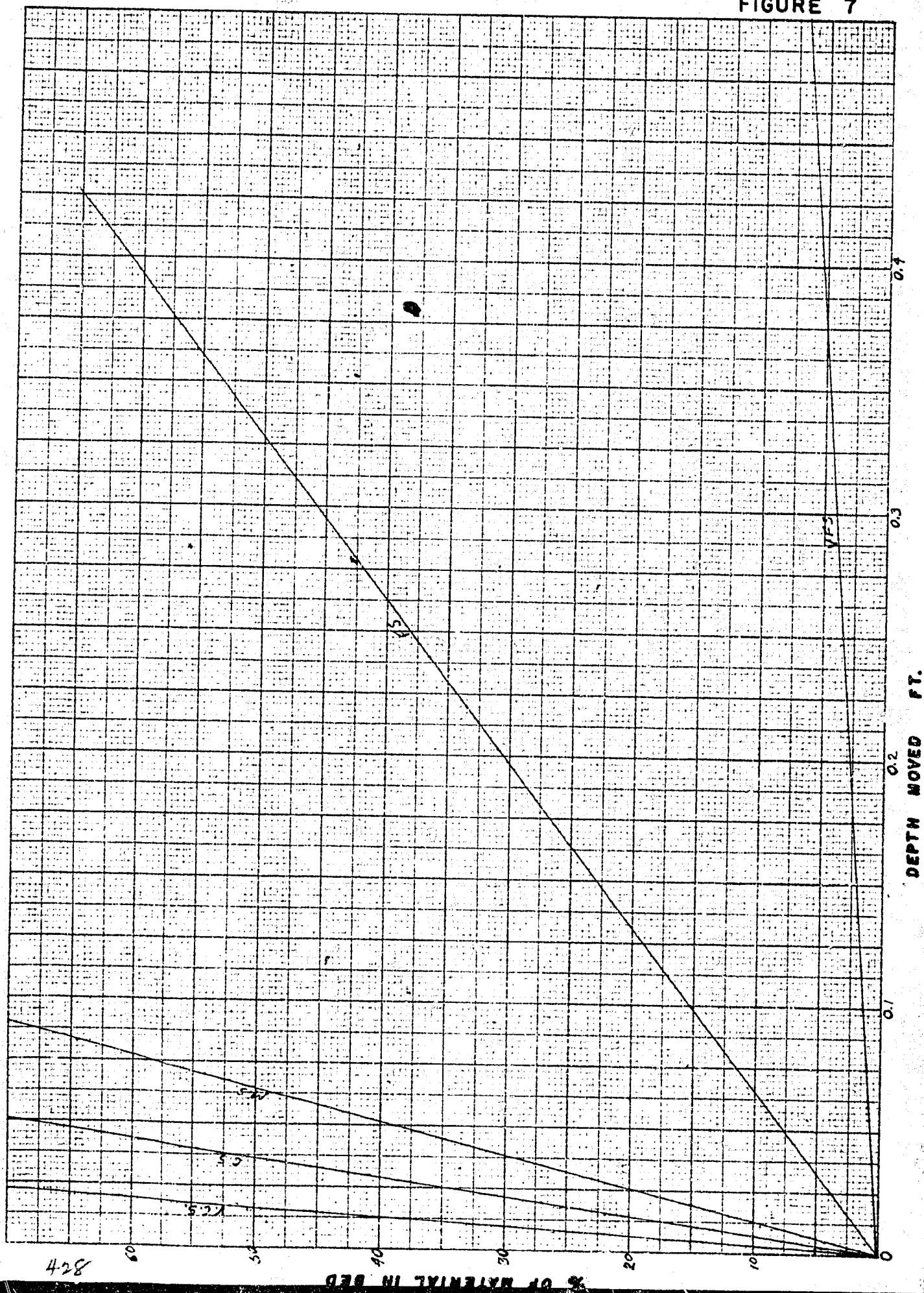


Table 1\*

RIO GRANDE DEGRADATION STUDIES  
DEGRADATION CALCULATION

	SILT	VPS	FS	MS	CS	VCS	VFG	FG	MG	TOTAL DEPTHS INFECT
<u>1st year</u>										
1. Percent in bed	:1.4	:4.9	:31.0	:42.8	:13.1	:3.2	:1.6	:1.4	:0.6	:
2. Depth in bed**	:0.098	:0.343	:2.170	:2.996	:0.917	:0.224	:0.112	:0.098	:0.042	:7.000
3. Depth entering from upstream	:0.052	:0.397	:0.207	:0.068	:0.015	:0.003	:0.002	:	:	:0.744
4. Depth entering from trib	:	:0.018	:0.028	:0.008	:0.004	:	:	:	:	:0.058
5. Depth diverted	:	:0.160	:0.097	:0.006	:	:	:	:	:	:0.263
6. Total available	:0.150	:0.598	:2.308	:3.066	:0.936	:0.227	:0.114	:0.098	:0.042	:7.539
7. Depth removed	:0.150	:0.364	:0.203	:0.055	:0.009	:0.001	:	:	:	:0.782
8. Depth remaining	:	:0.234	:2.105	:3.011	:0.927	:0.226	:0.114	:0.098	:0.042	:6.757
9. Percent remaining	:	:3.5	:31.1	:44.6	:13.7	:3.5	:1.7	:1.5	:0.6	:
10. Average percent	:0.7	:4.2	:31.0	:43.7	:13.4	:3.3	:1.6	:1.5	:0.6	:
11. Depth removed (average)	:0.150	:0.315	:0.203	:0.056	:0.009	:0.001	:	:	:	:0.734
12. Depth remaining	:	:0.283	:2.105	:3.010	:0.927	:0.226	:0.114	:0.098	:0.042	:6.805
13. Degradation	:0.098	:0.060	:0.065	:0.014	:0.010	:0.002	:0.002	:	:	:0.195
<u>2nd year</u>										
1. Percent in bed	:4.2	:30.9	:44.2	:13.6	:3.3	:1.7	:1.5	:0.6	:	:
2. Depth in bed	:0.283	:2.105	:3.010	:0.927	:0.226	:0.114	:0.098	:0.042	:6.805	:
3. Depth entering from upstream	:0.046	:0.149	:0.074	:0.020	:0.004	:0.002	:	:	:	:0.295
4. Depth entering from trib	:0.018	:0.028	:0.008	:0.004	:	:	:	:	:	:0.058
5. Depth diverted	:	:0.008	:0.001	:	:	:	:	:	:	:0.008
6. Total available	:0.347	:2.274	:3.091	:0.951	:0.230	:0.116	:0.098	:0.042	:7.149	:
7. Depth removed	:0.315	:0.209	:0.057	:0.010	:0.001	:	:	:	:	:0.592
8. Depth remaining	:0.032	:2.065	:3.034	:0.941	:0.229	:0.116	:0.098	:0.042	:6.557	:
9. Percent remaining	:0.5	:31.5	:46.2	:14.4	:3.5	:1.8	:1.5	:0.6	:	:
10. Average percent	:2.4	:31.2	:45.2	:14.0	:3.4	:1.7	:1.5	:0.6	:	:
11. Depth removed (average)	:0.170	:0.206	:0.058	:0.010	:0.001	:	:	:	:	:0.445
12. Depth remaining	:0.177	:2.068	:3.033	:0.941	:0.229	:0.116	:0.098	:0.042	:6.704	:
13. Degradation	:0.106	:0.037	:0.023	:0.014	:0.003	:0.002	:	:	:	:0.101
<u>3rd year</u>										
1. Percent in bed	:2.7	:30.9	:45.2	:14.0	:3.4	:1.7	:1.5	:0.6	:	:
2. Depth in bed	:0.177	:2.068	:3.033	:0.941	:0.229	:0.116	:0.098	:0.042	:6.704	:
3. Depth entering from upstream	:0.046	:0.119	:0.071	:0.022	:0.004	:0.002	:	:	:	:0.264
4. Depth entering from trib	:0.018	:0.028	:0.008	:0.004	:	:	:	:	:	:0.058
5. Depth diverted	:	:0.007	:0.001	:	:	:	:	:	:	:0.008
6. Total available	:0.241	:2.208	:3.111	:0.967	:0.233	:0.118	:0.098	:0.042	:7.018	:
7. Depth removed	:0.200	:0.202	:0.058	:0.010	:0.001	:	:	:	:	:0.471
8. Depth remaining	:0.041	:2.006	:3.053	:0.957	:0.232	:0.118	:0.098	:0.042	:6.547	:
9. Percent remaining	:0.6	:30.6	:46.6	:14.6	:3.6	:1.8	:1.5	:0.7	:	:
10. Average percent	:1.7	:30.7	:45.9	:14.3	:3.5	:1.8	:1.5	:0.6	:	:
11. Depth removed (average)	:0.125	:0.201	:0.059	:0.010	:0.001	:	:	:	:	:0.396
12. Depth remaining	:0.116	:2.007	:3.052	:0.957	:0.232	:0.118	:0.098	:0.042	:6.622	:
13. Degradation	:0.061	:0.061	:0.019	:0.016	:0.003	:0.002	:	:	:	:0.082

\*See explanation of table on Page 22.

\*\*All depths in feet



RIO GRANDE DEGRADATION STUDIES  
EXPLANATION OF DEGRADATION CALCULATIONS

- Line 1. Bed gradation in percent by weight.
- Line 2. Depth of each size in turnover zone assuming gradation by weight to be the same as the gradation by volume.
- Line 3. Depth shown on Line 11 of preceding stretch times (area of stretch) / (area of preceding stretch).
- Line 4. Depth of material from tributaries computed by dividing total inflow from watershed in proportion to area of watershed drained by this stretch.
- Line 5. One-half the concentration of suspended load in preceding stretch assumed as concentration of sediment in diverted water.
- Line 6. Lines 2 plus 3 plus 4 minus Line 5.
- Line 7. Read from ray diagram using percentage in Line 1.
- Line 8. Line 6 minus Line 7.
- Line 9. Size gradation of remaining material shown in Line 8.
- Line 10. Average of Line 1 and Line 9.
- Line 11. Read from ray diagram using percentages in Line 10.
- Line 12. Line 6 minus Line 11.
- Line 13. Line 2 minus Line 12.

Next period same as above starting with depths shown in Line 12 for Line 2; Line 1 will be size gradation as shown by Line 2.